2012

A HYDROLOGIC CHARACTERIZATION OF THREE HEADWATER MOUNTAIN WETLANDS IN EASTERN KENTUCKY, USA

Catherine Hoy
University of Kentucky, hoy_catherine@hotmail.com

STUDENT AGREEMENT:

I represent that my thesis or dissertation and abstract are my original work. Proper attribution has been given to all outside sources. I understand that I am solely responsible for obtaining any needed copyright permissions. I have obtained and attached hereto needed written permission statements(s) from the owner(s) of each third-party copyrighted matter to be included in my work, allowing electronic distribution (if such use is not permitted by the fair use doctrine).

I hereby grant to The University of Kentucky and its agents the non-exclusive license to archive and make accessible my work in whole or in part in all forms of media, now or hereafter known. I agree that the document mentioned above may be made available immediately for worldwide access unless a preapproved embargo applies.

I retain all other ownership rights to the copyright of my work. I also retain the right to use in future works (such as articles or books) all or part of my work. I understand that I am free to register the copyright to my work.

REVIEW, APPROVAL AND ACCEPTANCE

The document mentioned above has been reviewed and accepted by the student's advisor, on behalf of the advisory committee, and by the Director of Graduate Studies (DGS), on behalf of the program; we verify that this is the final, approved version of the student's dissertation including all changes required by the advisory committee. The undersigned agree to abide by the statements above.

Catherine Hoy, Student

Dr. Chris Barton, Major Professor

Dr. David Wagner, Director of Graduate Studies

A HYDROLOGIC CHARACTERIZATION OF THREE HEADWATER MOUNTAIN WETLANDS IN EASTERN KENTUCKY, USA

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Masters of Science in Forestry in the College of Agriculture at the University of Kentucky

By

Catherine Hoy

Lexington, Kentucky

Director: Dr. Chris Barton, Associate Professor of Forestry

Lexington, Kentucky

2012

ABSTRACT OF THESIS

A HYDROLOGIC CHARACTERIZATION OF THREE HEADWATER MOUNTAIN WETLANDS IN EASTERN KENTUCKY, USA

Three small (< 1 ha) mountain wetlands located in eastern Kentucky, host populations of two rare orchids, the white fringeless orchid, *Platanthera integrilabia,* and the crested yellow orchid, *Platanthera cristata*. Recently, concern has arisen about the persistence of the orchids. To better understand these wetlands and determine if hydrology is affecting the orchid populations, a hydrologic characterization study was initiated in 2009. Each wetland was equipped with a well nest consisting of piezometers, tensiometers, and a shallow well with a data logging pressure transducer. Chemistry and stable isotopes analysis (deuterium and ^{18}O) of groundwater and precipitation were analyzed, and soil, topographic and channel cross-section surveys were conducted. Hydrology data suggest the primary source of water is precipitation and the primary output is evapotranspiration. Between 10 and 30 cm below the soil surface soil and tensiometer data revealed the presence of a weak fragipan, which likely contributes to seasonal ponding at the site. Management recommendations include thinning and construction of debris dams to increase the hydroperiod, surface area, and total potential volume of the wetlands.

KEYWORDS: mountain wetland, hydrology, *Platanthera*, stable isotopes, topography

Catherine Hoy

April 9, 2012

A HYDROLOGIC CHARACTERIZATION OF THREE HEADWATER MOUNTAIN WETLANDS IN EASTERN KENTUCKY, USA.

By

Catherine Hoy

_______Dr. Chris Barton_________
Director of Thesis

______Dr. David Wagner________
Director of Graduate Studies

__________April 9, 2012_________

ACKNOWLEDGEMENTS

The work presented in this thesis could not have been possible without the help and guidance of many people. I would like to thank my co-advisors Dr. Chris Barton and Dr. Carmen Agouridis for their encouragement, help and support throughout graduate school. Also, I'd like to thank Dr. Mary Arthur for serving as a member of my committee.

Nik Eiche helped me with all of my field work and Emma Witt shared her resources, time and expertise; I couldn't have done it without them. Millie Hamilton, Alex Fogle, Dr. Christopher Romanek, Teri Dowdy and the Natural Resource Conservation Service helped me with my data analysis and interpretation.

Funding and support was provided by the United States Department of Agriculture Precision Resource Management Program and the Kentucky State Nature Preserve Commission (KSNPC). I am grateful for the help that I received from several members of the KSNPC staff, in particular, Joyce Bender, Zeb Weese, Tara Littlefield, and Martina Hines.

TABLE OF CONTENTS

Acknowledgements………………………………………………………... iii

List of Tables………………………………………………………………. v

List of Figures……………………………………………………………… vi

Chapter 1: Introduction……………………………………………………. 1
The Orchids……………………………………………………….... 2
The Wetlands…………………………………………………….. 3
Hydrology…………………………………………………………...... 5
Impact of Vegetation Change on Hydrology……………………….. 8
Water Quality, Stable Isotopes and Water Source Identification…….. 9
Topographic Maps and Cross-Sections……………………………….. 11
Penman-Monteith Equation………………………………………… 12
Site Description……………………………………………………….. 13
Purpose………………………………………………………………... 15

Chapter 2: Methods………………………………………………………... 16
Piezometers, Tensiometers and Pressure Transducers……………….. 16
Water Quality Analysis………………………………………………... 17
Stable Isotope Analysis………………………………………………... 19
Topographic Maps…………………………………………………….. 19
Cross-Sections………………………………………………………… 19
Penman-Monteith Model……………………………………………. 20
Soils…………………………………………………………………… 22
Statistics……………………………………………………………… 22

Chapter 3: Results/Discussion…………………………………………….. 24
Well Nests……………………………………………………………... 24
Soil……………………………………………………………………….. 36
Isotope and Water Chemistry…………………………………………. 38
Topography…………………………………………………………… 43

Chapter 4: Conclusion…………………………………………………… 53

Appendix………………………………………………………………….... 56
Appendix 1: Channel Cross-Section Summary……………………….. 56
Appendix 2: Channel Cross-Sections…………………………………. 58

Bibliography/References…………………………………………………….. 77

Vita………………………………………………………………………… 85

LIST OF TABLES

Table 3.1. VHG calculations (cm/cm) for piezometers ……………..…………………. 30

Table 3.2. Field classification and characteristics of soils………………………….. 37

Table 3.3. Statistical analysis results comparing the slopes of each site to each other and each site to precipitation (P)………………………………….. 41

Table 3.4. Summary of water quality averages and statistical results from Kruskal-Wallis and Mann-Whitney test using a p-value of 0.05 and n = 60.……. 42

Table 3.5. Average Δ in area below bankfull in cross-section surveys from 2010 to 2011 for all sites…………………………………..……………….. 44

LIST OF FIGURES

Figure 2.1.	Piezometer and well placement within well nests at each site……….	16
Figure 3.1.	Hydrographs for Site 1, 2 and 3 from February 24, 2010 to August 4, 2011…………………………………………………………………	24
Figure 3.2.	Water table readings for the 30 cm, 60 cm, 90 cm, and 120 cm piezometers and well from February 24, 2010 to August 4, 2011…….	25
Figure 3.3.	Manual piezometer readings for Sites 1, 2 and 3 from February 24, 2010 to August 4, 2011………………………………………………..	29
Figure 3.4.	Tensiometer readings for Sites 1, 2 and 3 from February 24, 2010 to August 4, 2011……………………………………………………...…	31
Figure 3.5.	Water Budget (precipitation and evapotranspiration) with precipitation normals for the study area from January 2010 to July 2011…………………………………………………………………	33
Figure 3.6.	Monthly Water Yield at study area and Potential Water Yield for LAI 1-5………………………………………………………………..	36
Figure 3.7.	Stable isotope analysis of deuterium (^{2}H) and oxygen (^{18}O) for the precipitation and surface water at sites 1, 2 and 3 with regional meteoric water line……………………………………………..……..	39
Figure 3.8.	Isotope analysis of deuterium (^{2}H) and oxygen (^{18}O) for the precipitation and surface water at sites 1, 2 and 3…………………….	41
Figure 3.9.	Cross-section survey for Site 2, cross-section 1...………………………	44
Figure 3.10.	Topographic Maps for Site 1……………………………….…………	46
Figure 3.11.	Topographic Maps for Site 2………………………………………….	47
Figure 3.12.	Topographic Maps for Site 3………………………………………...	48
Figure 3.13.	Example of a debris dam used to hold back water in a wetland………	49
Figure 3.14.	Site 1Stage-Storage Graph…..………………………………………..	50
Figure 3.15.	Site 2 Stage-Storage Graph….………………………………………..	50
Figure 3.16.	Site 3 Stage-Storage Graph…..………………………………………..	51

Chapter 1. INTRODUCTION

Since European settlement, approximately half of all wetlands in the United States have disappeared and in some states the loss has been even more drastic; nearly 80% of Kentucky's wetlands have been disturbed or destroyed (Mitsch and Gosselink, 1993). Despite legislation to protect remaining wetlands, North America has continued to experience losses, although the rate has decreased significantly (Mitsch and Gosselink, 1993). In recent years, the importance of wetlands has gained greater attention because of the benefits they provide for society and the environment, which make them crucial elements of any landscape. Such benefits provided by wetlands include waste treatment, flood control, recreation, nutrient cycling and habitat for many rare and endangered species. In a period in which climate change and environmental conservation are at the forefront of concern, the preservation, enhancement and restoration of wetlands have become a priority.

Forested wetlands of the southeastern United States are home to many plants and animals that are listed, or candidates for listing, under the Endangered Species Act (Ernst and Brown, 1989; Mitsch and Gosselink, 1993). They are the most important habitat for rare species, especially rare plants, in the southeastern United States (Murdock, 1994). Two of these rare species, the white fringeless orchid (*Platanthera integrilabia* Correll (Luer)) and the crested yellow orchid (*Platanthera cristata* Mischx. (Lindl.)), have been found in three seasonal headwater mountain wetlands in eastern Kentucky. This project examines and characterizes the hydrology of these unique wetlands in order to provide helpful information for future management of these rare orchid species.

THE ORCHIDS

The white fringeless orchid, *P. integrilabia*, is a terrestrial orchid with small white flowers that bloom around mid-August in Kentucky. It was historically common in the Cumberland Plateau physiographic region until the 1950s when it is thought that over collection caused a decline in their numbers (Zettler, 1994). Habitat alteration and hydrologic changes due to logging, construction and development have also contributed to their decline (T. Littlefield, pers. comm.). It is a candidate for listing under the Endangered Species Act and considered rare in the state of Kentucky (Ogle and Somers, 2008; KSNPC, 2011). Today there are only 30 known populations in 5 states, having been completely eliminated from North Carolina, Alabama and Mississippi (T. Littlefield, pers.comm.).

The crested yellow orchid (*P. cristata*) has a wider range than the white fringeless orchid, as it extends from Texas to New Hampshire (NRCS PLANTS Database). In the twenty states that the crested yellow orchid can be found, six of them list it as either endangered or threatened (NRCS PLANTS Database). A small herbaceous plant with yellow flowers, which also blooms in mid-August, it is considered threatened in the state of Kentucky (KSNPC, 2011).

Both species are perennial, obligate (OBL) wetland species and depend on a moist environment to survive (USFWS, 1988). They are commonly found growing in close association with each other in bogs of southern Appalachia (Zettler and Fairley, 1990; Zettler and McInnis 1994; Zettler et al., 1996; Currah et al., 1997; Zettler and Hofer, 1998). This close association and common habitat may be due to the utilization of a common mycorrhizal fungus, *Epulorhiza inquilina*, for seed germination, development and growth (Currah et al., 1997).

THE WETLANDS

Mountain wetland systems of the southeastern United States have not been thoroughly studied and information about them is limited in the literature. They are uncommon in the landscape, but they have features similar to those of other wetland types (Murdock, 1994; Pitillo, 1994; Thompson et al., 2007; Stine et al., 2011). Like most wetlands, mountain wetlands have hydric soils, wetland vegetation, and hydrologic indicators that meet criteria outlined in the Army Corps of Engineers 1987 Wetland Identification and Delineation Manual (Mitsch and Gosselink, 1993). Hydric soils are defined as those that "form under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part of the soil" (Hurt and Carlisle, 2001). Hydrologic indicators necessary for confirming wetland hydrology must demonstrate evidence of inundation or the influence of water on vegetation and soils of the wetland at some point during the growing season (ACE, 1987). Wetland vegetation must be dominated by facultative wetland (FACW) and OBL wetland species (Hurt and Carlisle, 2001).

Mountain wetlands are usually small in size (<5 ha) and either forested or marshy depending on the hydrology (Batzer and Sharitz, 2006; Stine et al., 2011). The classification of this wetland type as a "mountain wetland" is vague. Forested mountain wetlands have been referred to as bogs, fens and/or seasonal pools (Brooks and Hayashi, 2002; Thompson et al, 2007). Grouping these together into the single description of “mountain wetland” is unwise because the hydrology of these systems varies enough to form distinct ponding patterns that support unique faunal and floral communities.

Many headwater mountain wetlands of the Appalachian region are referred to as seeps which are characterized in the literature as locations where subsurface water sources emerge above ground level (Soulsby et al., 2007). They tend to be slightly acidic, occur at high elevations and have permanently saturated to intermittently dry soils (Weakeley and Schafale, 1994; O’Driscoll and DeWalle, 2010).

Other wetland types found in Appalachia are mountain bogs and fens. These wetland types are similar to each other because they accumulate peat, tend to hold water year round, and can maintain a range of vegetation, from grass and sedge dominated to completely forested (Mitsch and Gosselink, 1993). They differ based on hydrologic inputs and connection to groundwater systems. A fen describes a non-depressional wetland that is connected to the local groundwater system (Kolka and Thompson, 2006). In contrast, bogs do not have any significant inflows or outflows and rely on precipitation as their main hydrologic input (Kolka and Thompson, 2006). They are not connected to ground water systems, but are the result of a perched water table (Batzer and Sharitz, 2006).

The perched water that is found in bogs and some seasonal pools is usually the result of a restrictive layer in the soil which is sometimes referred to as a fragipan, hardpan or aquiclude. It is found at variable depths in the soil and is usually completely or partly impenetrable to water, inhibiting downward movement of water and promoting horizontal flow (Hillel, 1998; Hall et al., 2001; Schwarts and Zhang, 2003). This can create a perched water table and saturated conditions.

A seasonal wetland/pool refers to a broad range of wetlands that are often dry during the growing season, and saturated the remainder of the year (Mitsch and Gosselink, 1993; Korfel et al., 2010). They receive water mostly from precipitation, but can also have connections to groundwater (Mitsch and Gosselink, 1993; Kolka and Thompson, 2006). Hydrologic outputs of seasonal wetlands are primarily linked to evapo-transpiration with some water loss resulting from surface runoff and interflow (Kolka and Thompson, 2006). Seasonal saturation is extremely important for many amphibians, invertebrates and plants which use these wetlands as breeding grounds or require seasonally saturated conditions for reproduction (Brooks and Hayashi, 2002). These different types of mountain wetlands can be easily confused, therefore accurate analysis and descriptions are necessary for their management.

HYDROLOGY

Hydrology is considered the most important factor of wetland formation and persistence (Entry et al., 1995), therefore characterization of wetland hydroperiod is of great importance. A hydroperiod describes the frequency, depth and duration of seasonal flooding and/or saturated soil conditions of a wetland (Hulsmans et al., 2007). It is depicted by a hydrograph which displays the change in water level over a period of time. To characterize the hydrology of a system and create a hydrograph, one can use data collected from a combination of wells, piezometers and tensiometers. When used together in a single location, they are referred to collectively as a well nest.

Many studies have used well nests to document changes in water table levels after wetland restoration activities (Cooper et al., 1998; Moorhead et al., 2008; Rossell et al., 2009). This technology was also used in a study observing the changes in hydrology of an Appalachian fen during a drought in North Carolina (Moorhead, 2003).

Wells are drilled into the ground at a desired depth and screened along the entire length to allow water to enter. They are used to detect the presence of water in the soil by measuring the hydraulic head (Δh), or depth to water (Barackman and Brusseau, 2004). This may be done manually or using an automatic data logger attached to a pressure transducer. Using a data logger allows for frequent readings and produces more accurate and continuous data. A piezometer differs from a well in that it is only perforated at the base of the casing, therefore it only measures hydraulic head at the depth to which it is drilled into the ground and not the entire length of the soil profile (Barackman and Brusseau, 2004). They are usually installed in groups and at different depths, which allows for an approximation of where the water table lies below ground. They are also used to determine vertical and/or lateral groundwater movement. Soil matric potential quantifies the amount of pressure found between soil particles (Hillel, 1998). It has been defined as “the negative gauge pressure, relative to the external gas pressure on soil water, to which a solution identical in composition with the soil solution must be subjected in order to be in equilibrium through a porous membrane wall with the water in the soil” (Hillel, 1998). When water availability decreases, the pressure decreases due to the water film around soil aggregates becoming thinner (Chowdhury et al., 2011). A tensiometer is used for measuring soil matric potential and is an effective way to measure water availability. They are typically installed at the same depths as the piezometers within a well nest (Yolcubal et al., 2004). The use of this equipment is well documented in the literature and has many applications.

A study in southeastern Kentucky used well nests consisting of piezometers at depths of 30 cm, 60 cm and 90 cm to characterize the hydrology of three mountain wetlands. It was found that the water level of the 90 cm piezometer was consistently higher than that of the 30 cm and 60 cm piezometers (Thompson et al., 2007). From this data it was concluded that there was a groundwater contribution at a depth of 90 cm (Thompson et al., 2007). This is a classic example of using piezometers to determine the depth at which groundwater contributes to a system's hydrology.

A combination of piezometers and wells were used in a study of an Appalachian floodplain and associated fen to determine vertical hydraulic gradient (VHG) (Moorhead, 2001). VHG is the change in hydraulic head along a vertical flow path, and can be used to understand the direction of flow in groundwater (Barackman and Brusseau, 2004). By comparing the hydraulic head in the well to the hydraulic head in the piezometers, Moorhead was able to determine if upwelling or downwelling from groundwater occurred in the fen. The exact equation used was VHG = ($\Delta h_{piezometer} - \Delta h_{well}$)/depth to piezometer screen (Lee and Cherry, 1978). Upwelling is determined from a positive VHG, and is an indicator of aquifer discharge (Moorhead, 2001). Conversely, a negative VHG is indicative of downwelling, which is caused by aquifer recharge (Moorhead, 2001). This is an acceptable way to use piezometers and wells to determine the presence of groundwater contribution in a wetland. When there is no difference in hydraulic head between the piezometers and the well, it can be concluded that groundwater contribution is negligible.

In a western Kentucky study, Karathanasis and others (2003) used piezometers and tensiometers to characterize the hydrology of four seasonal wetlands. Tensiometers at lower depths had more negative readings than those at higher depths, suggesting that the soil was more saturated closer to the soil surface. In this case, the presence of a fragipan or restrictive fragic soil horizon explained the soil saturation closer to the soil surface. In addition, this study demonstrated the benefit of using tensiometers and soil matric potentital as an indicator of hydroperiod due to their sensitivity in assessing the duration of hydroregimes.

IMPACT OF VEGETATION CHANGE ON HYDROLOGY

Many studies have shown that silvicultural practices may alter the hydrology of a forested wetland (Sun et al., 2001; Amataya et al. (a), 2006; Amataya et al. (b), 2006; Barton et al., 2008). Harvesting can have variable effects but generally causes a decrease in evapo-transpiration and an increase in water yield, peak flows, and nutrient/sediment movement (Sun et al., 2002; Amataya et al. (b), 2006; Barton et al., 2008). Following a harvest, an area formerly possessing hydric soils can regain saturated conditions due to the abrupt decrease in transpiration (Mitsch and Gosselink, 1993). In a study on Carolina bay depressional wetlands, well nests were used to monitor the water level changes after tree removal and restoration activities (Barton et al., 2008). Increased hydroperiods were attributed to lower water demand due to reductions in transpiration within the wetlands and decreased infiltration due to soil compaction from logging equipment (Barton et al., 2008). Similar findings have been described on cypress-pine flatwoods in northern Florida (Sun et al., 2000).

But the wet conditions following wetland harvest may only be temporary, as woody plants start to invade during dry years and water levels tend to decline (Mitsch and Gosselink, 1993). Encroachment of hardwoods after a disturbance is a common phenomenon in southern wetland forests (DeSteven, 1991; Martin and Kirkman, 2009; Stine et al., 2011). It has been found to cause a considerable decline in herbaceous cover and herbaceous species diversity (Warren et al., 2007). Encroachment may be restricted by increasing the hydroperiod of a wetland, as seen in a study on Carolina Bays that found that wetlands with longer hydroperiods tended to have less hardwood regeneration (Moser, 2009).

WATER QUALITY, STABLE ISOTOPES AND WATER SOURCE IDENTIFICATION

Water quality analysis is an effective tool for determining the overall health of a natural system. Major and minor ions have also been used as trace parameters to understand the movement of groundwater in a system (Lloyd and Heathcote, 1985). As precipitation moves through the ground, reactions with soil and bedrock change the water chemistry. Usually the water will have higher levels of cations (e.g. Ca^{2+} and Mg^{2+}), higher levels of nitrogen, higher conductivity and a higher pH than the precipitation (Hall et al., 2001). Based on the degree of similarity or dissimilarity in the water chemistry of precipitation and surface water samples, it is possible to determine the presence of groundwater. Water samples from wetlands with a groundwater influence experience significantly different water chemistry from the precipitation, whereas wetlands without groundwater contribution have relatively similar water chemistry compared to precipitation.

Stable isotopes are also commonly used in hydrology for flow system tracing and water source identification. It is an accurate way of determining if a wetland is ombrotrophic (precipitation-fed) or minerotrophic (stream-fed). Usually combinations of oxygen-18 (^{18}O), deuterium (^{2}H), carbon-13 (^{13}C) or sulfur-34 (^{34}S) are used in shallow groundwater studies (Schwartz and Zhang, 2003; Carriera et al., 2011). Water retains its isotopic signature unless mixed or diluted with waters of different isotopic signatures (Fontes, 1980). Therefore stable isotope analysis allows for accurate water source identification (Yin et al., 2011).

Many studies have successfully used ^{18}O and ^{2}H from precipitation and groundwater to trace and characterize water sources of wetlands (DeWalle et al., 1997). Isotope analysis has become an integral part of hydrological studies in the past twenty years by providing essential information on hydrologic pathways and water source identification (Soulsby et al., 2007). Matheney and Gerla (1996) used stable isotopes to determine the origin and age of ground and surface waters of the Lunby and Stewart wetland in North Dakota. Using the isotopic signatures from precipitation samples, they created a regional meteoric water line specific to their site. A regional meteoric water line is a line created with precipitation stable isotope data for a specific area over time. It demonstrates the range of values during different seasons. The regional meteoric water line created by Matheney and Gerla (1996) allowed an for approximation of the average isotopic composition of the water infiltrating the wetland which was then compared to the data collected from the surface and groundwater to see if similarities existed. Ayalon et al. (1997) also used isotopic signatures of rainfall and the appropriate regional meteoric water line to determine the composition of the water in a karstic system in Israel.

TOPOGRAPIC MAPS AND CROSS-SECTIONS

Topographic maps are a three dimensional representation of the earth's surface and are an important tool in environmental monitoring, especially hydrology and wetland science (Hendricks, 2004). Recently, the importance of addressing topography in wetland restoration projects has been noticed because of the influence it has on the structure and function of a system (Rossell et al., 2009). The maps can be used to delineate a watershed, determine the direction of groundwater flow, and to calculate the total surface area and total potential volume of a wetland (Hendricks, 2004; Brooks and Hayashi, 2002). A study on vernal pools in New England characterized the relationship of surface area and volume on hydroperiod. Volume was calculated using the equation $V_{max} = A_{max} * d_{max} / [1 + (2/p)]$, where V_{max} is maximum volume associated with maximum depth, A_{max} is maximum area or extent of the pools, d_{max} is maximum depth and p represents the average basin shape or profile (Brooks and Hayashi, 2002). Using topographic data, ArcMap, and an equation similar to one used by Brooks and Hayashi (2002), it is possible to calculate the total surface area as well as the volume at different depths in a wetland. This is useful for planning restoration activities aimed at expanding the area and volume of a wetland.

Stream cross-sections represent the dimension (e.g. width and depth) of a stream along a transect. Temporal evaluations of stream cross-sections can help determine if channels are undergoing incision or aggregation. This can be determined using cross-section surveys taken from several transects along a channel over time and comparing the difference in area below bankfull from year to year. A study in northern California used cross-section surveys to examine the effects of culvert removal from forest roads over a three year period (Maurin and Stubblefield, 2011). The authors used the surveys to determine if there was a change in cross-sectional area from year to year which would indicate erosion or sedimentation. Other studies have used change in cross-sectional area to determine the effects on stream incision. Pearson et al. (2011) found that removing a 4 meter dam caused an initial response of channel incision, erosion and channel widening but eventually stabilization occurred. It seems that after a disturbance resulting in increased water yield, incision and channel degradation are common trends. However, at some point the channels stabilize and incision/degradation slow significantly, except for large rain events which undoubtedly cause higher rates of incison/degradation.

PENMAN MONTEITH EQUATION

Evapo-transpiration is one of the most challenging hydrologic parameters to estimate (Hulsmans et al., 2007), but it is a necessary component to quantify in order to fully understand the hydrology of a wetland. Measurement of evapo-transpiration can be accomplished through direct methods, such as pan evaporation and the diurnal method, or empirical estimates (which tend to be more cost-effective and more practical in wetlands) such as the Thornthwaite equation, Hammer and Kadlec equation or the Penman-Monteith equation (Mitsch and Gosselink, 1993). The Penman-Monteith model is based on Dalton’s law and the energy budget (Mitsch and Gosselink, 1993) and has been used in hydrological projects ranging from forests to agricultural lands, to determine the contribution of evapotranspiration to the overall water budget (Leudeling and Buerkert, 2008; Zhao et al., 2010). The monthly variables required by the Penman-Monteith model include: minimum and maximum temperature, solar intensity, minimum and maximum humidity and windspeed. Although this model requires several climatic variables that are not always available, it allows for daily and monthly evapotranspiration values to be determined for smaller areas, which is uncommon in most evapotranspiration models (Sun et al., 2011).

SITE DESCRIPTION

This study characterizes three mountain wetlands (elevation = 292 meters) located in eastern, Kentucky within the Cumberland Plateau physiographic region. Information detailing the location of the study area is not disclosed due to the sensitive nature of the plants. The wetlands within the study area are referred to as Site 1, Site 2 and Site 3 and have a drainage area of 4.01, 0.99 and 1.56 hectares, respectively. The area has a growing season that lasts approximately 179 days between April and October and receives an average precipitation of 122 cm (Web Soil Survey). In the early 1990's all three wetlands were logged but the western site (Site 3) was not logged as heavily (Shea, pers. comm.). After the harvest the orchids were revealed and the land was acquired by the KSNPC in 2003. The land has been left to regenerate naturally and a thick understory of young hardwoods now occupy the site.

The vegetation at the study area is dominated by red maple (*Acer rubrum*), black gum (*Nyssa sylvatica*), American holly (*Ilex opaca*), tulip poplar (*Liriodendron tulipifera*), white oak (*Quercus alba*), royal fern (*Osmunda regalis*), and cinnamon fern (*Osmunda cinnamomea*) (T. Littlefield, pers. comm.). Wetland indicator status categorizes plants into groups that reflect the probability of that plant being found in a wetland. OBL species, such as the white fringless orchid and the yellow crested orchid, occur almost always under natural conditions in wetlands (NRCS PLANTS Database). FACW species have a 67-99% probability of being found in natural wetland conditions, facultative (FAC) species are equally likely to occur in wetlands or non-wetland areas, and facultative upland (FACU) species are usually found in non-wetlands with a 1-33% probability of being found in natural wetlands (NRCS PLANTS Database). The wetland indicator status of American holly, tulip poplar, and white oak is facultative upland (FACU); red maple and black gum are facultative (FAC); cinnamon fern is facultative wetland (FACW) and royal fern is an obligate wetland (OBL) species (USFWS, 1988).

Concern has arisen recently that the wetlands are drying out and adversely affecting the orchid populations. Personal observations by KSNPC staff have indicated that the area was wetter and the orchid populations were larger in the past (J. Bender, pers. comm.). The KSNPC conducted a vegetation survey for *P. integrilabia* in 2009 and 2010 to document changes that may be attributed to changing hydrology at the sites. This report shows that the number of vegetative plants and flowering plants for the center wetland (Site 2) decreased from 2009 to 2010 (T. Littlefield, pers. comm.). In the upper portion of the eastern wetland (Site 1), there was an increase between 2009 and 2012 and very little change in the lower eastern wetland (T. Littlefield, pers. comm.). No plants were found at the western wetland (Site 3) in either 2009 or 2010 (T. Littlefield, pers. comm.). Many years of vegetation data will be necessary to make any solid conclusions about the orchids' status, but it is apparent that changes have occurred since the land was first acquired in 2003 (M. Hines, pers. comm.).

Mitsch and Gosselink (1993) state that hydrology plays a critical role in wetland form and function. Therefore, it is necessary to understand the hydrologic interactions of the wetlands to create and implement appropriate management activities aimed at restoring/preserving the orchid populations.

PURPOSE

The purpose of this project was to characterize the hydrology of three headwater mountain wetlands in eastern Kentucky. The specific objectives include: 1) Determine the influence of soils on hydroperiod, 2) Determine the origin of water and identify pathways for net water transformations (+ and –) in the system, and 3) Characterize channel formation below the wetlands and determine the level of influence the channels exert on hydrology (i.e. draining). This project was initiated in January 2010 and concluded in August 2011.

Chapter 2. METHODS

PIEZOMETERS, TENSIOMETERS AND PRESSURE TRANSDUCERS

Piezometers were used to measure hydraulic head at different depths within each site and were constructed of 2.5 cm diameter PVC piping with a 15 cm section of slotted (0.005 cm) PVC well casing on the submerged end. The pipes were bored into the ground at depths of 30, 60, 90 and 120 centimeters as seen in Figure 2.1. For each piezometer, the annulus of the hole was filled with sand and in-situ soil above the slotted pipe section, then sealed with a bentonite plug. The remaining annulus was filled with in-situ soil from borings. The hydraulic head from each piezometer was manually recorded in centimeters using the following equation: hydraulic head = distance from top of casing to ground – distance from top of casing to the depth of water.

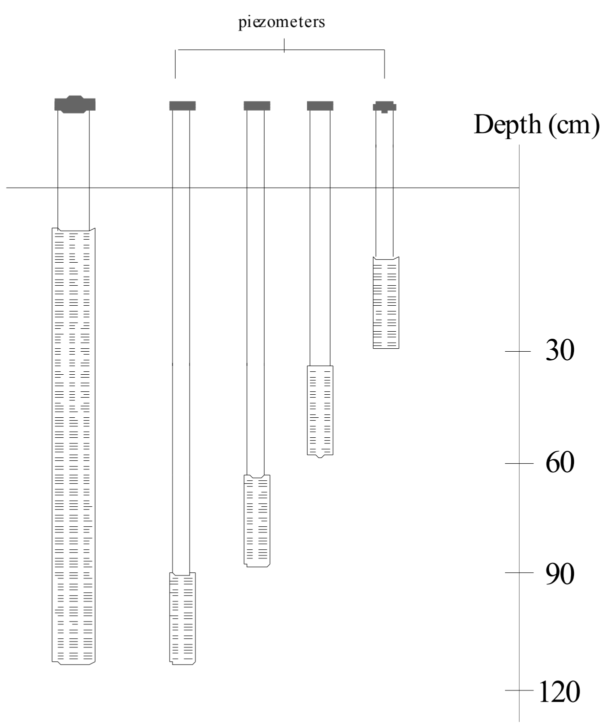


Figure 2.1 Piezometer and well placement within well nests at each site.

Tensiometers used to measure soil matric potential were constructed of a porous ceramic cup attached to a water column and vacuum gauge (Schwartz and Zhang, 2003). As water enters or exits the cup, depending on the saturation of the soil, the pressure head changes. A SW-010 tensimeter (Soil Measurement Systems, Tucson, AZ) was used to read the pressure in the tensiometer and the number was recorded in millibars; the more negative the reading, the drier the soil (Yocubal et al., 2004). The tensiometers were installed in a 2.5 cm hole at depths of 30, 60, 90 and 120 centimeters and then backfilled with native soil around the ceramic cup. Cement was used at the soil surface to hold the tensiometer in place and prevent short circuiting of water down the annulus of the hole.

A 150 cm slotted (0.005 cm) PVC well was installed at each site. The wells were constructed of 2.5 cm diameter PVC piping that was slotted the entire length. In-Situ MiniTROLL PSIG (In-Situ, Inc. Fort Collins, CO) pressure transducers recorded the water level in each well at 15 minute intervals. An In-Situ Rugged Reader was used to download the data, set up new tests and transfer the files to a computer where Microsoft Excel was used to create the continuous hydrograph for each wetland.

WATER QUALITY ANALYSES

A precipitation collector was constructed at the study site and placed in an open canopy location that was central to all the wetlands. The collector consisted of a funnel and a one-liter Nalgene collection bottle attached to a stand at a height of approximately six feet. Wool glass was placed inside the funnel to prevent bugs, leaves and other unwanted materials from contaminating the sample. The precipitation was collected bi-weekly and analyzed in the lab for cations, anions, alkalinity, pH, nitrates and total organic carbon.

A Nalgene mityvac pump was used to retrieve groundwater from the well for analysis on a bi-weekly basis. A YSI® environmental monitor (556 Model) (YSI, Inc. Yellow Springs, OH) was used to record the dissolved oxygen (DO), electrical conductivity (EC), temperature and pH at the time of collection. Well water samples were stored in a cooler for 2 hours when they were transported back to the lab and further analyzed following methods outline in Standard Methods for Examination of Water and Wastewater (Greenburg, 1992).

Total organic carbon (TOC) and dissolved organic carbon (DOC) were analyzed with a Shimadzu TOC 5000A Analyzer (Shimadzu Corporation, Maryland). The samples were unfiltered for TOC analysis and filtered for DOC analysis (0.45µm pore size). Calcium (Ca^{2+}), magnesium ($Mg2^{+}$), sodium (Na^{+}) and potassium (K^{+}) were measured using a GBC SDS 270 Atomic Adsorption Spectrophometer (AAS) (GBC Scientific Equipment, Illinois). A Dionex Ion Chromatograph (IC) 2000 (Dionex Corporation, California) was used to determine the concentrations of sulfate (SO_4^{2-}) and chloride (Cl^-). Alkalinity was found using an auto titrater with a tritrant endpoint pH of 4.6, and an Orion pH meter. Nitrate (NO_3^-N) and ammonium (NH_4^+-N) were analyzed using colorimetric analysis and a Bran+Luebbe Autoanalyzer (Bran+Luebbe, Analyser Division, Germany).

STABLE ISOTOPE ANALYSIS

Well water and precipitation samples were analyzed for stable isotopes ^{2}H and ^{18}O. The samples were filtered (0.45 μm pore size) into 12 x 32 mm auto-sampler vials and analyzed on a CRDS Isotopic Carbon Analyzer. The values obtained were used to create a scatter plot and a regional meteoric deviation line of the precipitation data, so as to compare with the surface water data.

TOPOGRAPHIC MAPS

Topographic maps were created using standard surveying procedures to characterize the microtopography of each site. The equipment used included a Sokkia 530R Total Station (accuracy: ±1" horizontal angle, ±5" vertical angle, ±2mm + 2ppm distance) and a Carlson Explorer II handheld data logger. Permanent benchmarks were established throughout the surveying process using guidelines described in Harrelson, et al. (1994). A boundary was established around each wetland and points were shot along transects perpendicular to the stream. Using ArcGIS version 9.2, the topographic maps were created and used to determine the direction of flow and to model the effects of a proposed debris dam on the total potential volume and total surface area of the wetlands.

CROSS-SECTIONS

Channel aggregation or degradation was monitored and quantified using annual stream cross-sections. Along the channel below each wetland, a series of 5-8 permanent cross-sections were installed. Cross-section surveys were conducted once in March of 2010 and again in May of 2011. Using RIVERMorph version 4.3 (REVERMorph LLC, Louisville, KY), the cross-section from 2011 was overlain on the respective cross-section from 2010. Bankfull was established and the change in area below bankfull was calculated from 2010 to 2011 to determine if there was a difference. A negative change in area is indicative of channel incision and a positive change is indicative of aggregation. Longitudinal profiles were also surveyed in March of 2010 and used to determine the slope of the channel.

PENMAN MONTEITH MODEL

Using precipitation and climate data from the Kentucky Mesonet website, mean daily reference evapotranspiration rates were calculated using a modified version of the Penman-Monteith equation (Monteith, 1965; Allen et al., 1999) with fixed parameters derived from the literature (Itenfisu et al., 2000; Walter et al., 2000). The equation used was:

$$ET_{ref} = \frac{0.408\Delta(R_n - G) + \gamma\frac{C_n}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

where Δ is the slope of the saturation vapor pressure at the mean air temperature (kPa $^{o}C^{-1}$), R_n and G are the net radiation and soil heat flux density (MJ $m^{-2}h^{-1}$), g is the psychrometric constant (kPa $^{o}C^{-1}$), T is the hourly mean temperature (^{o}C), u_2 is the hourly mean wind speed in m s^{-1}, and e_s-e_a is the vapor pressure deficit (kPa). The coefficients in the numerator (C_n) and the denominator (C_d) were chosen based on the reference crop of concern. Values for C_n vary depending upon the type of crop due to aerodynamic resistance differences and physiological functions in relation to water usage.

Inputs into the equation were obtained from weather data measured at the Kentucky Mesonet site. Data from the weather stations closest to the study area were used. Inputs included were daily mean solar radiation (MJ m^{-2} d^{-1}), air temperature (^{o}C), wind speed (m s^{-1}), and humidity (%). The latitude, longitude and elevation of the project site were utilized to determine constants for the equation as outlined by Allen et al. (1998). This model was selected for the project because it offered an evapotranspiration rate formulated for an open grassland (ET_o) or a tall canopy forest (ET_r), the latter being the most appropriate option for this site.

Sun et al. (2011) developed an equation to calculate monthly measured actual evapotranspiration (ET) using ET_o from the Penman Monteith model and leaf area index (LAI). The equation is as follows:

$$ET = 11.94 + 4.76LAI + ET_o(0.032LAI + 0.0026P + 0.15)$$

Where ET = actual average monthly evapotranspiration, LAI = leaf area index, ET_o = the average monthly evapotranspiration value calculated from the Penman Monteith equation for an open grassland, and P = monthly average precipitation. This equation determines ET for a specific area by incorporating LAI which can differ dramatically between sites with different forest cover and species composition. LAI is essentially a measure of canopy cover and is reported in m^2/m^2. Chen and Black (1992) define LAI as "one half the total leaf area per unit ground area". It is related to basal area and affects the rate of evapotranspiration, photosynthesis and microclimates (Weiss et al., 2004). LAI values around 5 have been reported for several temperate, deciduous forests at similar latitude and longitude as the study area. A value of 5 was used as the initial LAI for the study area in the equation from Sun et al. (2011). This number was based on similar forests in the southeastern United States whose LAI have been previously determined (Scurlock et al., 2001). LAI values of 4, 3, 2 and 1 were also calculated to model the effects of thinning and canopy reduction on the rate of evapotranspiration and the water budget.

SOILS

At each site, soils were excavated from a central location with a bucket auger and described and sampled by horizon following standard procedures (Schoeneberger et al., 2002). Soil samples were sealed in polyethylene bags for future physicochemical analysis. Subsequently, a small pit (approximately 40 cm in depth) was also excavated at each site to confirm the presence of fragic horizons.

Physical and chemical properties of samples from each horizon were determined at the University of Kentucky's Regulatory Services Soil Testing Laboratory. Air-dried sieved samples were analyzed for particle size by the pipette method (Sheldrick and Wang, 1993). Soil pH was measured in a 1:1 soil/water paste following methods outlined by the Soil and Plant Analysis Council (2000). Soil organic matter (SOM) was measured using a LECO CHN analyzer (Nelson and Sommers, 1982).

STATISTICS

The data for the water chemistry analyses were not normally distributed which required non-parametric tests for analysis. The Kruskal-Wallis test was used to determine differences among all samples (all three sites and precipitation) for each water quality parameter. If any differences were identified with the Kruskal-Wallis test, the

Mann-Whitney test was used to compare each site to each other and precipitation. A p-value of 0.05 was used for determining statistical significance.

Chapter 3. RESULTS/DISCUSSION

WELL NESTS

Hydraulic head was recorded and used to show the fluctuation of water level over the course of the study. Due to the copious amount of data, only the first reading of every day was used to create the hydrographs seen in Figure 3.1. The blue line represents the daily water level in the well at each site. Some data is missing due to equipment failure, but manual readings of hydraulic head taken during bi-weekly visits to the study area were used to fill in the gaps.

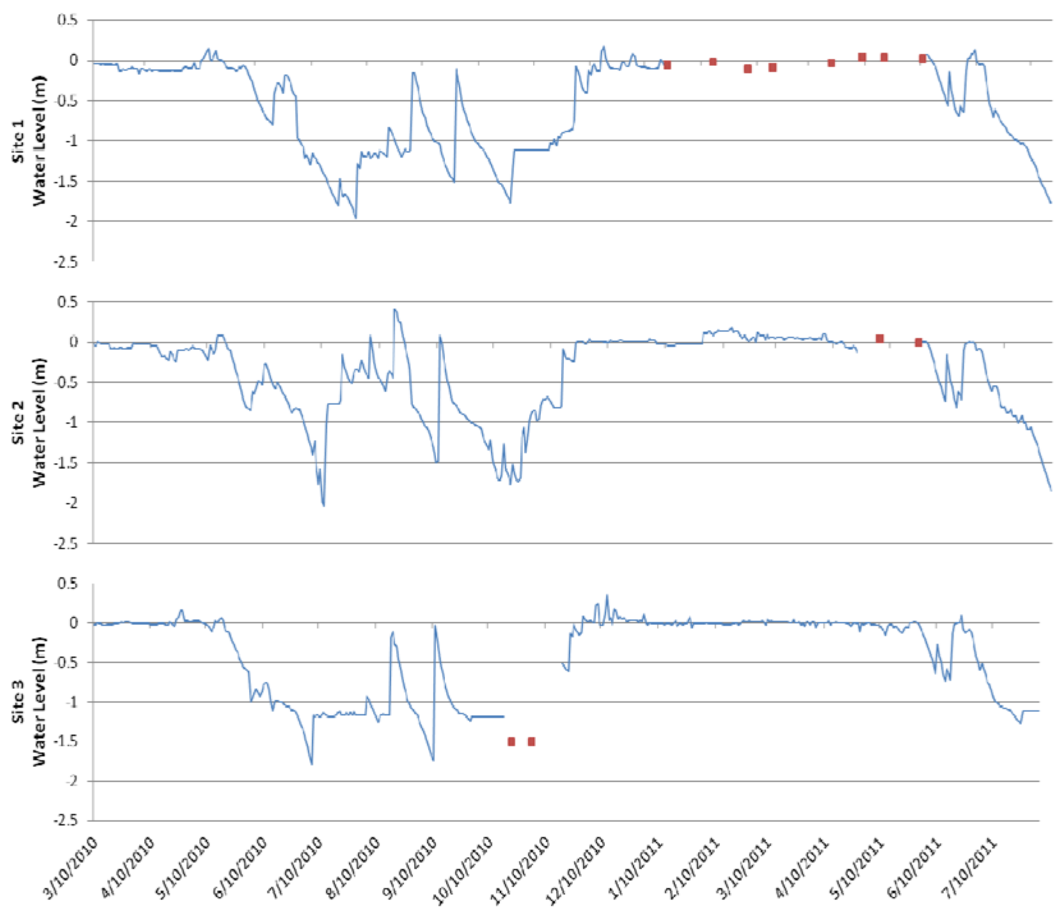


Figure 3.1. Hydrographs for Site 1, 2 and 3 from February 24, 2010 to August 4, 2011. †The blue line represents data collected with pressure transducers and the red boxes are data collected from manual readings.

Figure 3.2. compares the piezometer manual readings between the sites for the 30 cm, 60 cm, 90 cm, 120 cm piezometers and the well. The graphs in Figure 3.2. show a consistency in the water level fluctuations between the sites.

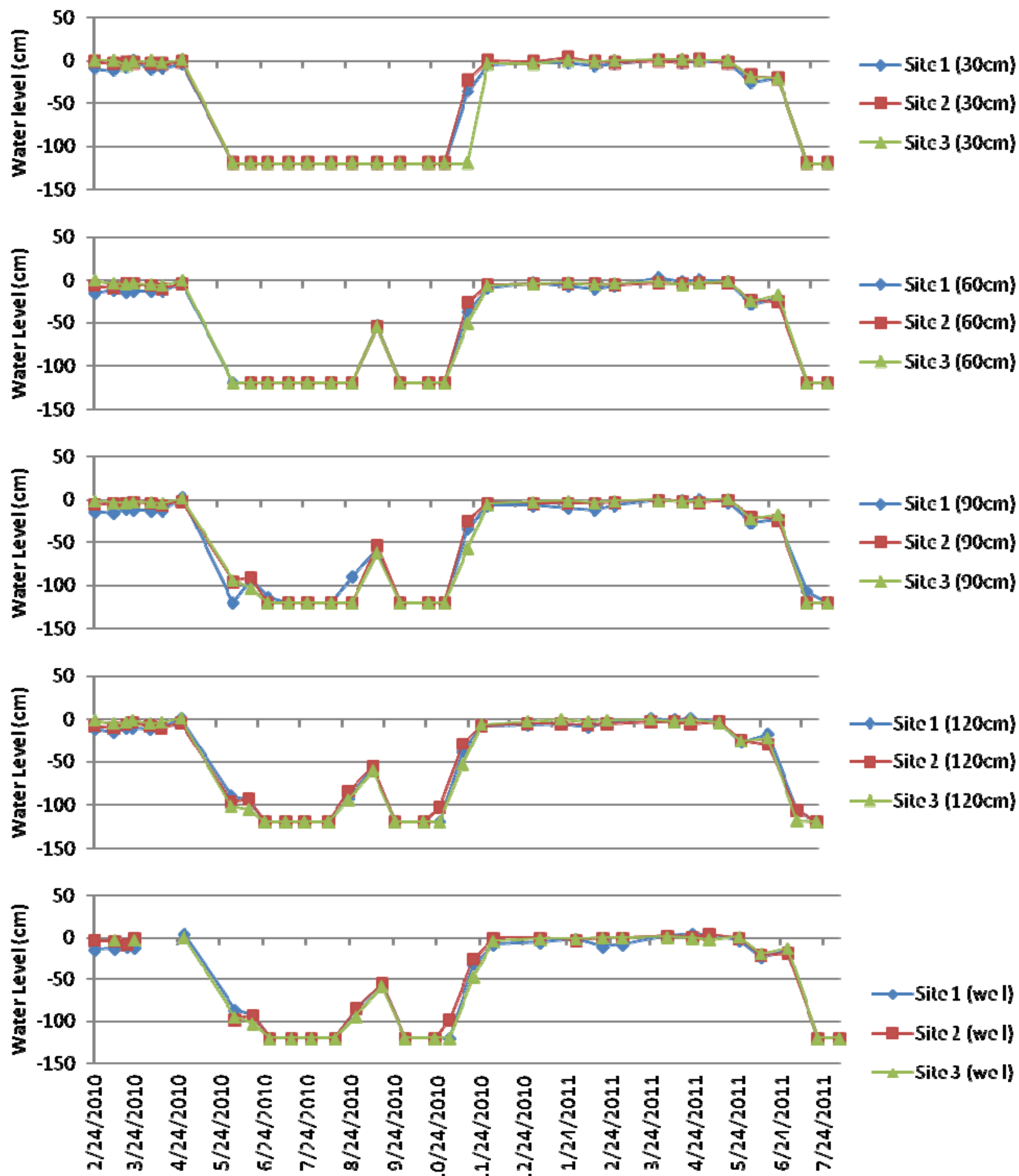


Figure 3.2. Water table readings for the 30 cm, 60 cm, 90 cm, and 120 cm piezometers and well from February 24, 2010 to August 4, 2011.
†The blue line represents data from Site 1, the red line represents data from Site 2, and the greed line represents data from Site 3.

The hydroperiod at each wetland (Figures 3.1 and 3.2) behaved in a similar manner over the course of the study, suggesting similar hydrologic regimes among the three sites. All sites maintained saturated conditions from the beginning of December through the end of May. During this time, the water level usually stayed between +/- 10 centimeters. Following saturation, there was a significant dry-down period from June until November. Occasional rain events during the dry season caused temporary saturation of the soil and are consistent among the hydrographs. Normally, the wetlands do not exceed a maximum water level of approximately 10 centimeters, with a couple of exceptions during large rain events on the hydrographs for sites 2 and 3 (Figure 3.1).

Site 1 was flooded for 9 days during the growing season in 2010 and 12 days in 2011. Site 2 was flooded for 12 days during the growing season in 2010 and 11 days in 2011. Site 3 was flooded for 20 days during the growing season in 2010 and 25 days in 2011. These numbers likely underestimate the number of days each wetland was flooded during the growing seasons of 2010 and 2011 due to missing data from the remainder of the growing season in 2011 and equipment failure at various times during the project. Site 1 and 2 reflect the high amount of precipitation received in 2011, as they have more days flooded during the growing season than in 2010. Site 3 has more days flooded during the growing season than Site 1 and 2. This may be attributed to the fact that it was not harvested as heavily as Site 1 and 2 (J. Bender, pers. comm.). Therefore, it does not host as dense of an understory which allows for more water to be diverted back into the wetland rather than towards evapotranspiration.

The predictable pattern of fluctuation is representative of seasonal wetlands as described by Mitsch and Gosselink (1993) and Korfel et al. (2010). The transition from dry conditions during the growing season to saturation during the winter months can be explained by the timing of senescence in the Autumn and leaf-on in the Spring, respectively. Studies have shown that the water level in forested wetlands can be controlled by the rate of evapotranspiration (Sun et al., 2000; Thompson et al., 2007; Barton et al., 2008). Seasonal wetlands tend to dry out during the growing season when leaves are actively transpiring water and regain their wetness in the winter when there are no leaves on the trees and evapotranspiration decreases (Thompson et al., 2007). This is true for the wetlands at the study area, which are completely saturated from November to May and dry out from June to October.

When compared to other mountain wetlands systems of southern Appalachia, the wetlands at the study area are similar in some respects but different in others. In a study examining two mountain wetlands in southeastern Kentucky, one in Blanton Forest State Nature Preserve and one located in Cumberland Gap National Historic Park, seasonal water level fluctuations were similar to the pattern observed at the wetlands in this study (Thompson et al., 2007). The wetland with the most drastic dry-down period, and also the most similar to the wetlands at the study area, also had the greatest water contribution from precipitation. Thompson et al, (2007) concluded that wetlands connected to groundwater tend to have less extreme fluctuations in their hydroperiods than wetlands that receive the majority of their water from precipitation. The hydroperiod of the wetlands at the study area fluctuated greatly during the study period suggesting a strong precipitation influence.

Not all mountain wetlands in the Appalachian region are precipitation fed and have seasonally variable hydroperiods. Francl et al. (2004) characterized 20 wetlands in

West Virginia and found that many of the wetlands remained saturated during long periods of the growing season. These wetlands are more similar to mountain bogs or mountain fens than the seasonal wetlands found at the study area where saturation during the growing season only occurred in early spring and after significant rain events. In addition, the wetlands at the study area differ from mountain bogs and mountain fens because peat accumulation that is commonly found in those systems is absent (Kolka and Thompson, 2006).

The piezometer graphs in Figure 3.3 represent manual water level measurements taken during bi-weekly visits to the study area. These graphs reiterate the seasonal pattern seen in Figure 3.2, but also show a very tight fit among the piezometers and well at each site. Table 3.1 represents one VHG calculation for the piezometers at each wetland during the winter, spring, summer and fall. A single day was selected for calculation of VHG that represented every season and selected days were approximately three months apart. The average VHG for Site 1 = -0.013 cm, Site 2 = -0.060 cm and Site 3 = -0.005 cm. The lowest VHG occurred on November 2, 2010 at Site 2, 30 cm piezometer and had a value of -0.73 cm. The highest VHG occurred at the same piezometer on January 30, 2011 and had a value of 0.21 cm.

In addition, there seems to be a wet period in the summer of 2010 around mid-September, which corresponds to a rain event seen in Figure 3.1. There is an increase in water level for the 60 cm piezometer, 90 cm piezometer, 120 cm piezometer and the 150 cm well. The 30 cm piezometer did not have standing water at the time of the manual reading. After the rain event water slowly infiltrated through the fragic horizon, and saturated the deeper soil horizons. Eventually the soil surface dried out, but at the time of sampling the layer of soil below the fragipan had not dried out yet.

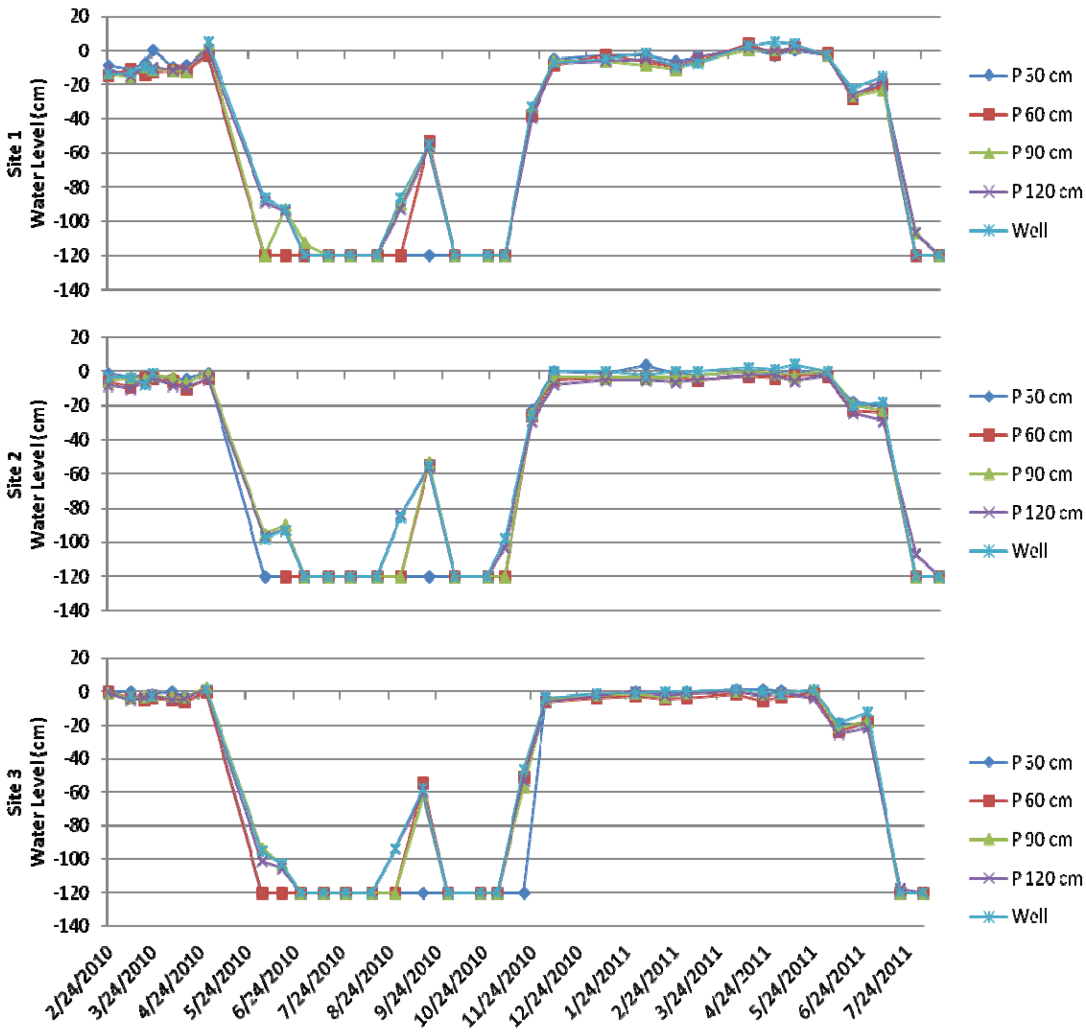


Figure 3.3. Manual piezometer readings for Sites 1, 2 and 3 from February 24, 2010 to August 4, 2011.

†The dark blue line represents data from the 30 cm piezometer, the red line represents data from the 60 cm piezometer, and the green line represents data from the 90 cm piezometer, the purple line represents data from the 120 cm piezometer and the light blue line represents data from the well.

Table 3.1. VHG calculations (cm/cm) for piezometers.

		Winter 2/24/10	Spring 4/28/10	Summer 8/13/10	Fall 11/2/10	Winter 1/30/11	Spring 5/4/11	Summer 8/4/11
Site 1	30 cm	0.17	-0.28	0.00	0.00	0.13	-0.13	0.00
	60 cm	-0.01	-0.13	0.00	0.00	0.00	-0.04	0.00
	90 cm	0.01	-0.02	0.00	0.00	-0.01	-0.03	0.00
	120 cm	0.02	-0.03	0.00	0.00	0.01	-0.02	0.00
Site 2	30 cm	0.08	-0.03	0.00	-0.73	0.21	-0.11	0.00
	60 cm	-0.04	-0.07	0.00	-0.37	-0.02	-0.12	0.00
	90 cm	-0.02	-0.02	0.00	-0.24	-0.01	-0.08	0.00
	120 cm	-0.04	-0.04	0.00	-0.04	-0.02	-0.09	0.00
Site 3	30 cm	0.00	0.00	0.00	0.00	-0.04	0.08	0.00
	60 cm	0.00	-0.02	0.00	0.00	-0.08	0.02	0.00
	90 cm	-0.01	0.01	0.00	0.00	-0.04	0.01	0.00
	120 cm	-0.01	0.00	0.00	0.00	-0.01	0.01	0.00

The tight fit seen in Figure 3.3 suggests that there is no groundwater influencing the hydrology of the wetlands. Otherwise, there would be differences in the water level between the piezometers and the well, depending on the depth at which groundwater is entering the system. This is confirmed through the VHG calculations in Table 3.1 which show that the differences between the well and piezometer manual readings are minimal. Using the methods outlined by Moorhead (2001) for determining VHG in wetlands, it was found that although there was some periodic wetting and drying, the values are small and do not suggest overall trends of discharge or recharge (Table 3.1). This suggests that groundwater has little or no influence in the wetlands at the study area.

The manual readings for the tensiometers at each site over the course of the study document changes in soil moisture (Figure 3.4). As the soil becomes drier, the readings become more negative due to more negative pressure in the tensiometer.

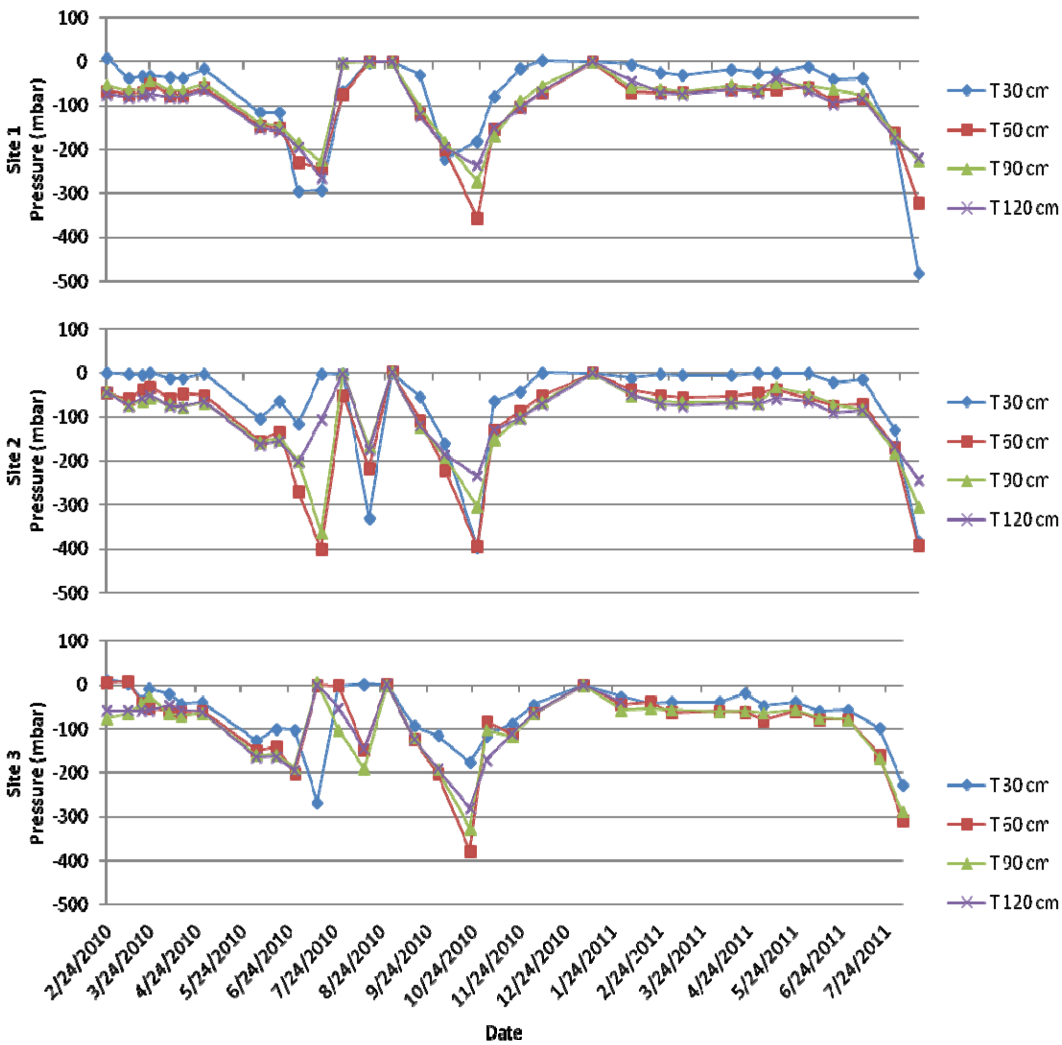


Figure 3.4. Tensiometer readings for Sites 1, 2 and 3 from February 24, 2010 to August 4, 2011.
†The blue line represents data from the 30 cm piezometer, the red line represents data from the 60 cm piezometer, the green line represents data from the 90 cm piezometer and the purple line represents data from the 120 cm piezometer.

The tensiometer graphs are similar to the piezometer graphs, showing wet and dry periods at similar times of the year. There is some incongruity between the piezometers and tensiometers, around August 2010, which shows saturation in the wetlands. This is due to two large rain events that are documented on the hydrographs (Figure 3.1). During the rain events, the soil became wet again and manual readings from the tensiometers documented the gradual drying of the soil over time. This sensitivity and accuracy of tensiometers has been documented in the literature (Karathanasis et al., 2003). Although ponding was absent, tensiometer data show that soils were saturated for a long period during the growing season which will help support OBL and FACW plants.

The tensiometer graphs also suggest the presence of a restrictive layer in the soil somewhere between 30 and 60 cm at sites 1 and 2. This is represented by a distinct separation in the readings between the 30 cm tensiometer and the 60, 90 and 120 cm tensiometers. The 60, 90 and 120 cm tensiometers had a more negative reading than the 30 cm tensiometer, indicating that the soil was wetter at the surface and suggesting that some kind of restrictive layer is causing the perched water. A similar pattern occurred at several seasonal wetlands in western Kentucky and led to the conclusion that a fragic horizon was responsible for the ponded water (Karathanasis et al., 2003). At Site 3, the pattern was less evident, suggesting the fragic horizon or restrictive layer has less of an influence on wetland hydrology which may contribute to the reduced numbers of orchids found at that site.

A water budget graph was constructed using monthly precipitation, monthly evapotranspiration and normal monthly precipitation values. During the wet, winter months precipitation was usually higher than evapotranspiration, and during the growing season evapotranspiration was usually higher than precipitation. Water yield can be estimated as the difference between precipitation input and evapotranspiration output (Sun et al., 2004; Figure 3.5), or all of the water not lost as evapotranspiration. This can be in the form of surface runoff in streams and channels, infiltration into the soil or sheet flow across the wetland which can be seen during the winter and spring months when the wetlands are saturated. The number of months with more precipitation than evapotranspiration is greater than those with less precipitation than evapotranspiration. This demonstrates a significant influence of precipitation on the wetlands and represents the months when the wetlands typically have saturated or ponded conditions.

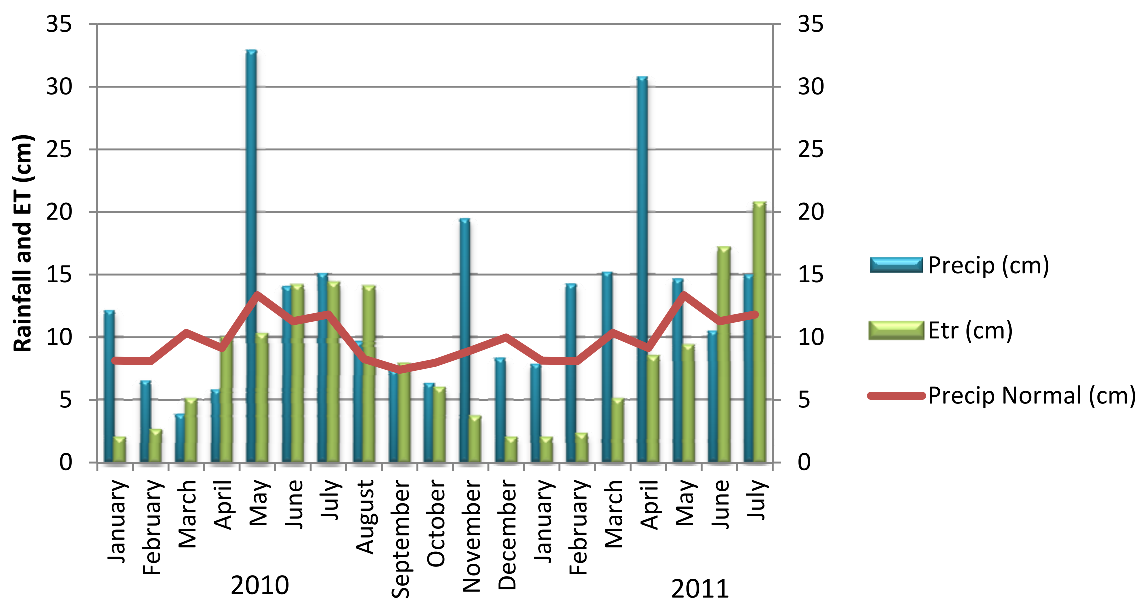


Figure 3.5. Water Budget (precipitation and evapotranspiration) with precipitation normals for the study area from January 2010 to July 2011.

Using data provided by the water budget graphs (Figure 3.5), a ratio of evapotranspiration/precipitation was calculated for the study area and was determined to be 0.58. Assuming that no water was lost to a groundwater source, this number was subtracted from 1 to give the water yield/precipitation ratio, which was 0.42. Similar results were found in a study examining upland forested watersheds in the southeastern

United States. Using the evapotranspiration and precipitation data, water yield to precipitation ratios were calculated. Three of the study sites were located in Kentucky and were very similar compared to the study area, with ratios of 0.42, 0.38 and 0.33 (Sun et al, 2004). Based upon the water budget, almost half of the water at the study area leaves the wetlands as surface runoff or infiltration, suggesting that there is a potential for incision or channel development in the streams below.

In addition, Figure 3.5 shows that 2011 was a particularly wet year. Five of the seven months that were recorded exceeded the precipitation normals for that area of Kentucky, which can affect hydroperiod, channel incision and the orchid populations. More rainfall contributed to a longer hydroperiod which as seen in Figures 3.1, 3.2 and 3.3. The wetlands did not completely dry out until the beginning of June in 2010, but in 2011 the extra rainfall postponed this until the beginning of July. Higher levels of precipitation can also lead to increased water yield which may cause increased stream flow in the channels exiting the wetlands. Even though there was more rainfall in 2011, it did not seem to have a significant effect on the rate of channel incision and/or degradation. This suggests that channel incision is not occurring at present; however, if management activities were to take place that increased water yield, channel incision will become an issue of concern. Finally, the increased water levels and hydroperiod may lead to a change in the orchid population at the study area, but because there is no data available on the most suitable water level and hydroperiod conditions for the orchids, it is hard to estimate what kind of effect increased precipitation will have.

It is thought that decreased hydroperiod and light availability, from the emerging understory, have contributed to the reduction in orchid populations over the years. A reduction in basal area at the study area is recommended to increase water yield to the wetlands, reduce evapotranspiration, and increase light availability for the orchids. Several studies have shown that thinning causes an increase in stream flow, as well as an increase in evapotranspiration (Sun et al., 2002; Amataya et al. (b), 2006; Barton et al., 2008). Although the light requirements for the orchids are not known specifically, they are mostly found in partially shaded bogs and benefit from at least some sunlight (Zettler and Fairey, 1990; Zettler and McInnis 1994; Zettler et al., 1996 (a); Zettler and Hofer, 1998). The wetlands at the study area are heavily shaded and could be thinned out to create a more appropriate light environment for the orchids while freeing up some of the water that goes to evapotranspiration.

To understand the effects of thinning and reduced canopy cover on the water budget, an equation from Sun et al. (2011) was used to calculate the monthly average actual evapotranspiration (ET). Using a range of values for LAI (1-5), ET was calculated for each month from January 2010 to July 2011. Water yield (precipitation - ET) for each LAI value (1-5) was then compared to the water yield calculated for the study area using the ET_r value calculated from the Penman Monteith equation (Figure 3.6). This figure shows that higher LAI values reduce the water yield due to increased evapotranspiration, whereas lower LAI values increase water yield. This suggests that LAI directly influences the hydrology and that reducing the basal area at the study area will create a longer hydroperiod in the wetlands. Once the actual LAI for the study area is determined, this model can help decide approximately how much thinning is necessary.

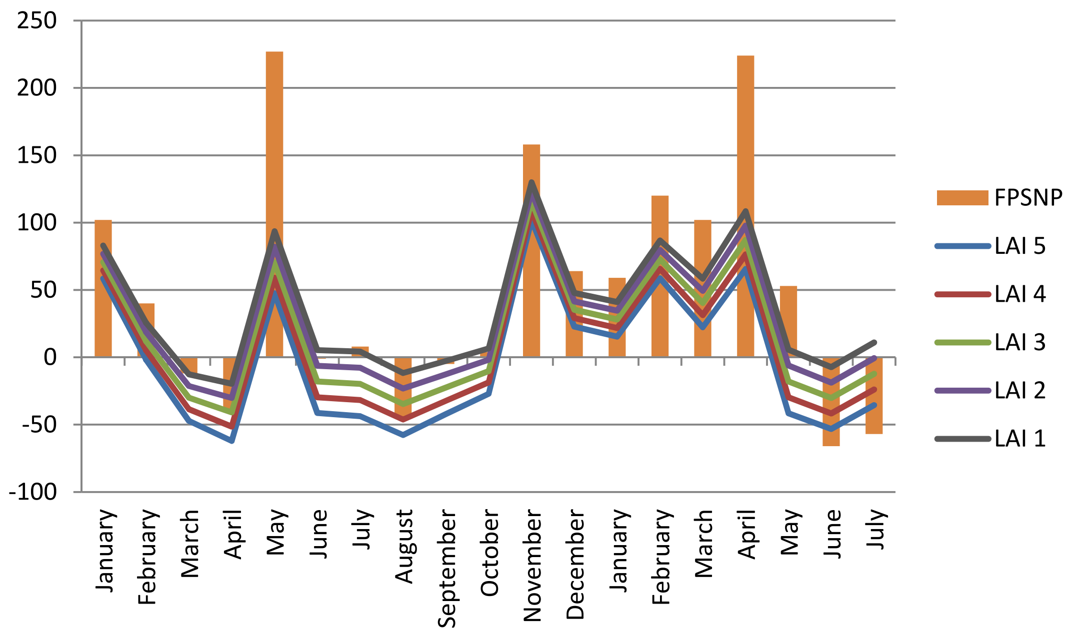


Figure 3.6. Monthly Water Yield at study area and Potential Water Yield for LAI 1-5. †Monthly water yield (precipitation – Etr) values for the study area are depicted by the orange line and potential water yield (precipitation – ET) values for a forest with LAI values ranging from 1-5 are depicted by the colored lines.

SOIL

In the soil survey for the county where the wetlands are found, created by the United States Department of Agriculture (1974), the soil of the study area is shown as a Jefferson-Shelocta-Muse, a soil association described as "well drained soil on very deeply dissected mountainous uplands with very steep slopes". This soil description is not appropriate for the soils found at the study site. Probably due to their small size, the wetlands were not mapped on the original soil survey. To gain a better understanding of the wetlands, soil surveys were conducted at each site (Table 3.2).

Soils at all three sites had similar texture and structure. A-horizons extended to depths of 10-11 cm, below which a weak fragic horizon (Bxg) was present between 10 and 30 cm. Matrix color and redox features were also similar among the sites. The pH of all the soils was slightly acidic with a range from 4.52 to 4.91. Soil organic matter (SOM) was highest at the soil surface and then decreased with depth. High SOM in the A horizon can be an indicator of wetland and hydric soils. The soils at the study area had similar SOM values as the Martins Fork wetland in Thompson et al. (2007) and some of the wetlands in the Karathanasis and others (2003) study in western Kentucky.

Table 3.2. Field classification and characteristics of soils.

Horizon	Depth (cm)	Matrix Color	Redox Feature Color†	Texture‡	StructureΔ	pH	SOM (%)*
			Site 1				
A	0-11	10YR 5/2	f,f, 10YR 4/4	sil	gr	4.74	4.88
Bxg	11-30	2.5Y 6/2	m,d, 7.5YR 5/6	sil	b,abk	4.66	1.17
Bw1	30-52	2.5Y 6/4	m,d, 7.5YR 6/8	sil	sbk	4.78	0.55
Bw2	52-90	2.5Y 6/6	m,d, 7.5YR 5/8	sil	sbk	4.91	0.43
C/R	90+						
			Site 2				
A	0-10	10YR 4/2		sil	gr	4.52	6.52
Bxg	10-25	2.5Y 6/2	f,d, 5YR 5/8	sil	b,abk	4.59	2.87
Bw1	25-40	2.5Y 6/3	m,f, 7.5YR 6/8	sil	sbk	4.74	1.03
Bw2	40-70	2.5Y 7/3	m,d, 10YR 5/8	sil	sbk	4.78	0.58
Bw3	70-95	2.5Y 7/2	m,f, 7.5 YR 6/8	sil	sbk	4.87	0.60
C/R	95+						
			Site 3				
A	0-10	10YR 4/2		sil	gr	4.55	6.45
Bxg	10-25	2.5Y 6/2	m,d, 7.5YR 5/8	sil	b,abk	4.62	1.63
Bw1	25-40	2.5Y 6/3	m,f, 7.5YR 6/8	sil	sbk	4.75	0.79
Bw2	40-60	2.5Y 6/3	m,d, 7.5YR 7/8	sil	sbk	4.80	0.60
Bw3	60-95	2.5Y 6/3	m,d, 7.5YR 5/8	l	sbk	4.81	0.41
Cg	95+	2.5Y 6/2	m,d, 7.5YR 5/8	l	ma	4.80	0.26

†Abundance: f=few, m=many; Brightness: f=faint, d=distinct.
‡Texture: sil=silt loam, l=loam.
ΔStructure: b=brittle, gr=granular, abk=angular blocky, sbk=subangular blocky, ma=massive.
*SOM=soil organic matter.

There are two main categories of hydric soils – organic soils and hydric mineral soils. Organic soils are characterized by a thick layer of organic matter (at least 40 cm) in the upper 81 cm of the soil and are usually referred to as mucks or peats (Hurt and Carlisle, 2001). Hydric mineral soils may also have an organic layer but are characterized mainly by the matrix chroma below the A horizon or within 25 cm of the surface, whichever comes first (ACE, 1985). To be considered hydric, they must have a matrix chroma of 2 or less in mottled soils or 1 or less in unmottled soils (ACE, 1985). Mottles are redoxomorphic features that can be red (redox concentrations) or grey (redox depletions) and are characteristic of hydric soils (Hurt and Carlisle, 2001). The wetland soils at the study area can be considered hydric due to the presence of mottles below the A horizon in addition to a Bxg horizon with a chroma of 2. Soil organic matter was greater in the A horizons than the B and C horizons, which is typical in wetlands where decomposition of organic materials is limited due to anaerobic conditions (Collins and Kuehl, 2001).

Results of the soil survey showed that soils were similar among all three wetlands, with a fragic horizon between 10 and 30 centimeters. A fragipan or hardpan is a subsurface horizon that restricts the movement of water and tends to have brittle properties (Hall et al., 2001). This may be the factor that is responsible for the perched water and seasonal saturation in the wetlands at the study site.

ISOTOPE AND WATER CHEMISTRY

Water source identification using stable isotopes is a relatively new strategy in the field of wetland science (Chagué-Goff et al., 2010). This is accomplished in wetland systems by comparing precipitation to surface water based on the differences or similarities in the isotopic signature of the samples (Matheney and Gerla, 1996; Ayalon et al., 1997; Yin et al., 2011).

A regional meteoric water line shows the range of isotopic signatures found in the precipitation for an area, which can change with temperature and season. Using the values obtained from the analysis of stable isotopes in the precipitation collected from the study area, a regional meteoric water line was created for the wetlands (Figure 3.7). The regional meteoric water line had a value of y = 7.5031x + 10.152 and $R^2 = 0.9782$. A slope of 7.5 suggests that there is an influence of evaporation on the system (Matheney and Gerla, 1996). The isotopic signature values of the groundwater samples were placed on the same graph as the values for the regional meteoric water line, and are represented by different symbols and colors, as seen in the legend. These values plot very close to or on top of the meteoric water line, which suggests a high degree of similarity between the wetland surface water and the precipitation.

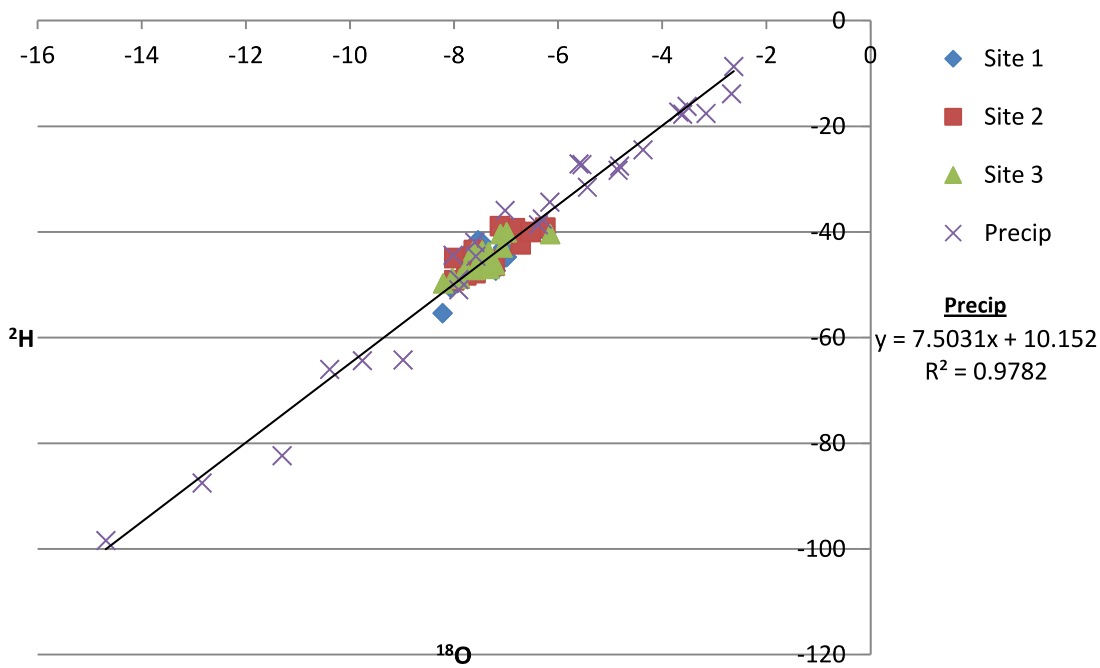


Figure 3.7. Stable isotope analysis of deuterium (^2H) and oxygen (^{18}O) for the precipitation and surface water at sites 1, 2 and 3 with regional meteoric water line.

The isotopic signature of the precipitation experiences some seasonal variation throughout the year, with values ranging from -2.63 (‰) to -14.69 (‰). Precipitation values during the growing season, when temperature and evapotranspiration is high, are typically less negative than values in the winter. Less negative numbers are indicative of samples with heavier ^{18}O and ^{2}H values. When water evaporates, the heavier isotopes remain in the solution, which causes it to become enriched (Chagué-Goff et al., 2010). Studies have documented this relationship between temperature and isotopic signature (Henderson et al., 2010). There is not as much variation among the sites in the surface water samples because water collection was restricted during the growing season due to lack of water and sometimes during the winter months due to freezing conditions.

Another isotopic signature graph was constructed to display only the values of precipitation that were within the range of the values from each site (Figure 3.8). This allowed for a comparison of the slopes between each site and between each site and the precipitation. Using methods similar to those described by the USEPA (1993) for a paired watershed statistical comparison, the slopes were analyzed to see if there were any statistical differences. It was found that the slopes of all three sites were not statistically different from each other and the slope of the precipitation was marginally different from the slope of each site (Table 3.3). These results suggest there is a small difference between the isotopic signature of each site and the precipitation.

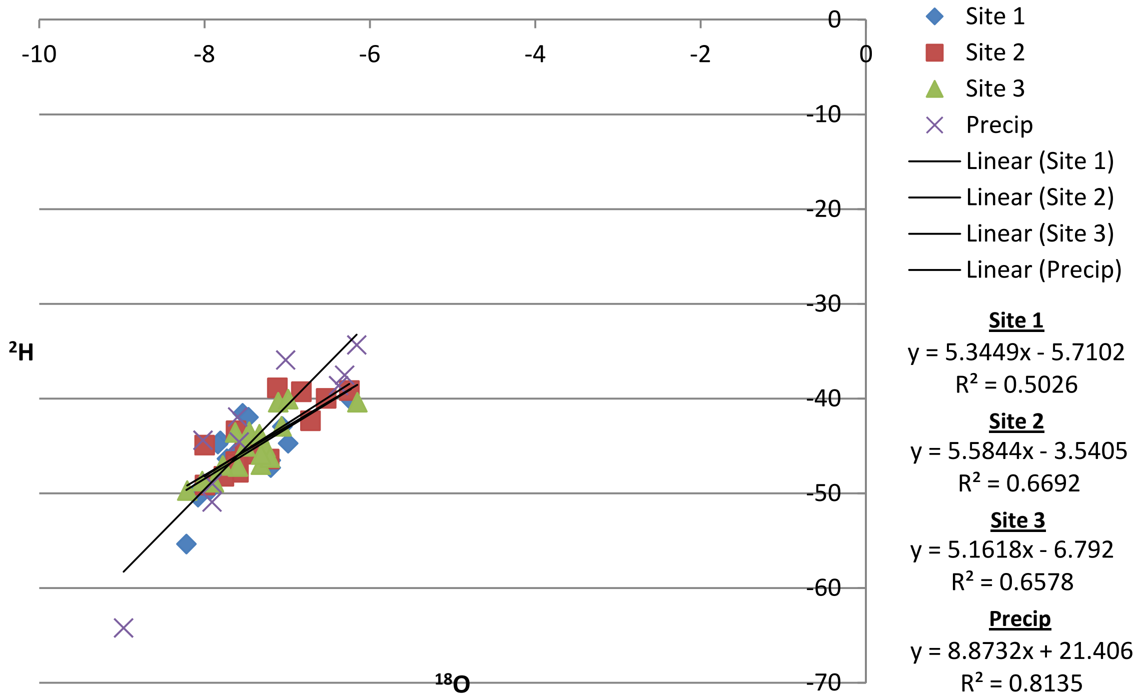


Figure 3.8. Isotope analysis of deuterium (^{2}H) and oxygen (^{18}O) for the precipitation and surface water at sites 1, 2 and 3.

Table 3.3. Statistical analysis results comparing the slopes of each site to each other and each site to precipitation (P)

	Site 1 vs. Site 2	Site 1 vs. Site 3	Site 2 vs. Site 3	Site 1 vs. P	Site 2 vs. P	Site 3 vs. P
p-value	0.88	0.912	0.758	0.103	0.088	0.068

The data presented in Table 3.4. displays the average water chemistry values of the samples collected from the precipitation and the wetlands over the course of the study. Data were only included in this table if there was a complete sampling for the site on that day, which included surface water from each site and precipitation. As such, sample dates correspond to the period of saturation in the hydrographs because water was not available for collection during most of the summer. The total number of sample dates included was fifteen, making a total of 60 samples. The water and precipitation at the study area is slightly acidic, has low conductivity and TOC, and low levels of cations, anions and nitrates. Although the statistics show several statistically significant differences among and between the sites and the precipitation, the values are close in magnitude.

Table 3.4. Summary of water quality averages and statistical results from Kruskal-Wallis and Mann-Whitney test using a p-value of 0.05 and n = 60.

	Site 1	Site 2	Site 3	Precip
Cl (mg/L)	1.60^{A} ± 0.63	1.67^{A} ± 0.99	1.68^{A} ± 0.68	0.86^{B} ± 0.50
SO_4 (mg/L)	7.90^{A} ± 8.41	5.68^{A} ± 3.33	5.38^{A} ± 2.86	3.75^{A} ± 3.43
Mg (mg/L)	0.37^{A} ± 0.11	0.34^{A} ± 0.11	0.35^{A} ± 0.15	0.07^{B} ± 0.04
Ca (mg/L)	0.56^{A} ± 0.18	0.48^{B} ± 0.16	0.56^{A} ± 0.14	0.32^{C} ± 0.26
K (mg/L)	1.26^{A} ± 1.06	1.17^{A} ± 1.35	1.32^{A} ± 0.14	0.25^{B} ± 0.37
Na (mg/L)	0.70^{A} ± 0.37	0.84^{A} ± 0.76	0.83^{A} ± 0.54	0.54^{A} ± 0.61
NO_3-N (mg/L)	0.05^{AC} ± 0.54	0.03^{BC} ± 0.03	0.01^{B} ± 0.02	0.10^{A} ± 0.13
NH_4-N (mg/L)	0.10^{A} ± 0.13	0.11^{A} ± 0.13	0.11^{A} ± 0.13	0.16^{A} ± 0.15
PO4 (mg/L)	0.30^{A} ± 0.45	0.23^{A} ± 0.43	0.09^{A} ± 0.10	1.2^{A} ± 2.08
Conductivity (uS/cm)	23.47^{A} ± 5.15	26.07^{A} ± 8.46	27.79^{A} ± 6.14	13.31^{B}± 5.45
Alk (mg$CaCO_3$eq/L)	7.59^{A} ± 2.44	7.53^{A} ± 2.51	7.08^{A} ± 2.58	8.70^{A} ± 6.67
pH	5.18^{A} ± 0.23	5.02^{AB} ± 0.17	4.95^{B} ± 0.15	5.63^{C} ± 0.51
TOC (mg/L)	3.52^{A} ± 1.21	5.58^{B} ± 2.15	6.46^{B} ± 2.70	2.94^{A} ± 1.60
DOC (mg/L)	2.58^{A} ± 0.91	3.90^{B} ± 1.37	4.87^{B} ± 2.08	NA

Comparing precipitation and wetland water chemistry at the study area, reinforced conclusions made from the stable isotope data; groundwater does not influence wetland hydrology. In a Carolina Bay study involving three wetlands that are mostly precipitation fed, Pickens and Jagoe (1996) reported similar differences between precipitation and water chemistry concentrations for anions and cations. The water chemistry of the precipitation and the wetlands were similar with some minor differences, which suggests that the wetlands are precipitation fed and the water is very clean (low conductivity and low ionic strength). In addition, the water chemistry among the wetlands is very similar, suggesting similar hydrology and soils at each site.

Mg, Ca and K concentrations were lower in the precipitation than in the surface water, indicating the water had some contact time with the soil. These numbers, however, are not considerably different which suggests that the contact time with the soil was low. NO_3-N and NH_4-N concentrations are higher in the precipitation than in the wetlands suggesting that some of the nitrogen is being utilized by the vegetation (Evangelou, 1998).

TOPOGRAPHY

Figure 3.9 is an example of a channel cross-section and Table 3.5. summarizes the values generated from cut fill analyses on the cross-sections. The Δ area represents the change in cross-sectional area below bankfull from the first survey in 2010 to the second in 2011. Bankfull describes the level at which a channel is completely filled without spilling over into its floodplain. A negative number indicates stream aggregation in between surveys, and a positive number indicates incision. The average change in cross-sectional area for all wetlands was 0.0028 m^2. The average change in area for Site 1 was -0.0140 m^2, Site 2 was 0.0112 m^2, and Site 3 was 0.0056 m^2. Graphs depicting all cross-sections are located in Appendix 2 and a more detailed table of the cut fill analyses for each cross-section can be found in Appendix 1.

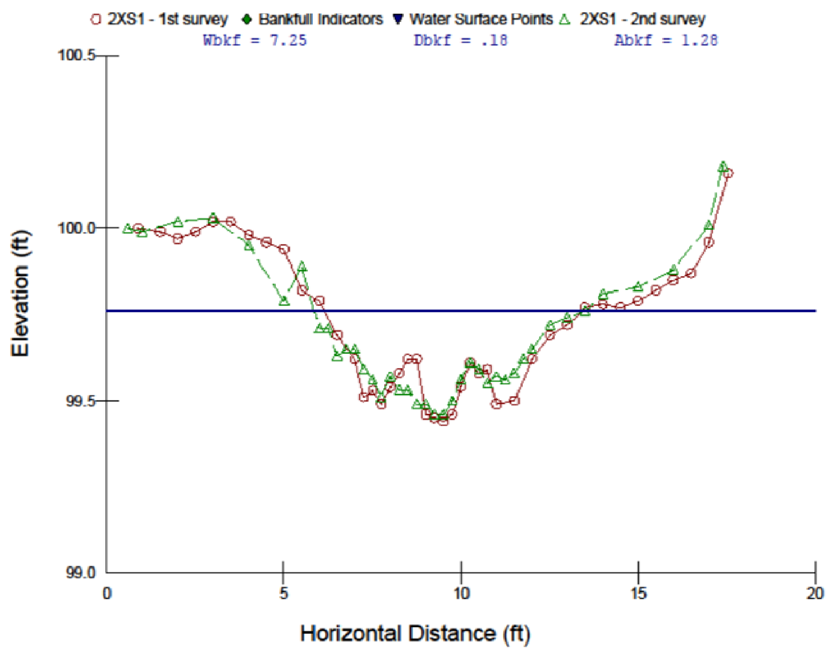


Figure 3.9. Cross-section survey for Site 2, cross-section 1.
†The red line represents the survey from 2010 and the green line represents the survey from 2011. The blue line represents bankfull.

Table 3.5. Average Δ in area below bankfull in cross-section surveys from 2010 to 2011 for all sites.

	Average Δ (m^2)	Aggregation/Incision
Site 1	-0.0140	Aggregation
Site 2	0.0112	Incision
Site 3	0.0056	Incision
All	0.0028	Incision

Changes in the cross-sectional area from 2010 to 2011 were quite small and potentially hard to differentiate from any measurement error that might have occurred. In a study examining channel adjustment after culvert removal in California, erosion and sedimentation were measured from year to year using similar methods and much higher rates of erosion and sedimentation were found, especially in the first year (Maurin and Stubblefield, 2011). Although the small numbers from the surveys do not suggest current trends of incision and/or aggregation, channel formation could have resulted from the previous harvest activities and associated response in hydrology. More data are necessary to verify this statement. It is recommended that the annual cross-section surveys be continued to generate a more accurate depiction of the influence of the channels on wetland hydrology. Two years of data are likely not enough to make a definite statement regarding aggregation and/or degradation of the channels.

Wetland topography is a key factor determining the structure and function of a wetland (Rossell et al., 2009). It is essential to understand the topography of the wetlands at the study area in order to make appropriate management decisions. The topographic maps (Figures 3.10 – 3.12) were helpful in understanding the direction of flow at each site as well as determining logistics for management. At present, there is normally very little standing water found in the wetlands. This may be the result of the stream being the lowest point which would cause draining and not allow the water to pond for long. Potential conditions after restoration activities which include thinning and building a debris dam can be seen in Figures 3.10 – 3.12. These maps represent the maximum water level that can be achieved assuming that precipitation is not limited. The placement of the debris dam was determined using the maps and personal observations based on where the wetlands begin to drain into the channels below. Using the closest cross-section to that area, the height of the debris dam was chosen as the height of the channel's bank (essentially where the floodplain begins). The expected outcomes for the wetlands under these management recommendations include: increased hydroperiod, increased total surface area and increased total potential volume.

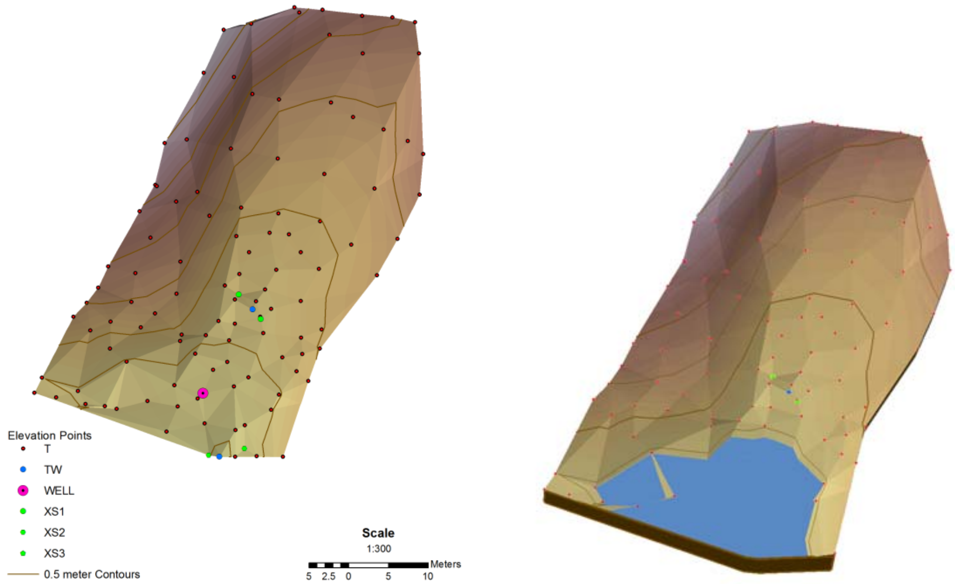


Figure 3.10. Topographic maps for Site 1.
†Present conditions are displayed on the left and potential conditions after restoration and are displayed on the right. The pink represents the well (WELL), the green dots represent the permanent benchmarks for cross-sections (XS), the blue dot represents the thalweg (TW) within each cross-section and the red dot represents each point that was surveyed (T). The contour lines are in 0.5 meter intervals and do not represent the actual elevation, but rather an elevation relative to the lowest point surveyed on the whole topographic map.

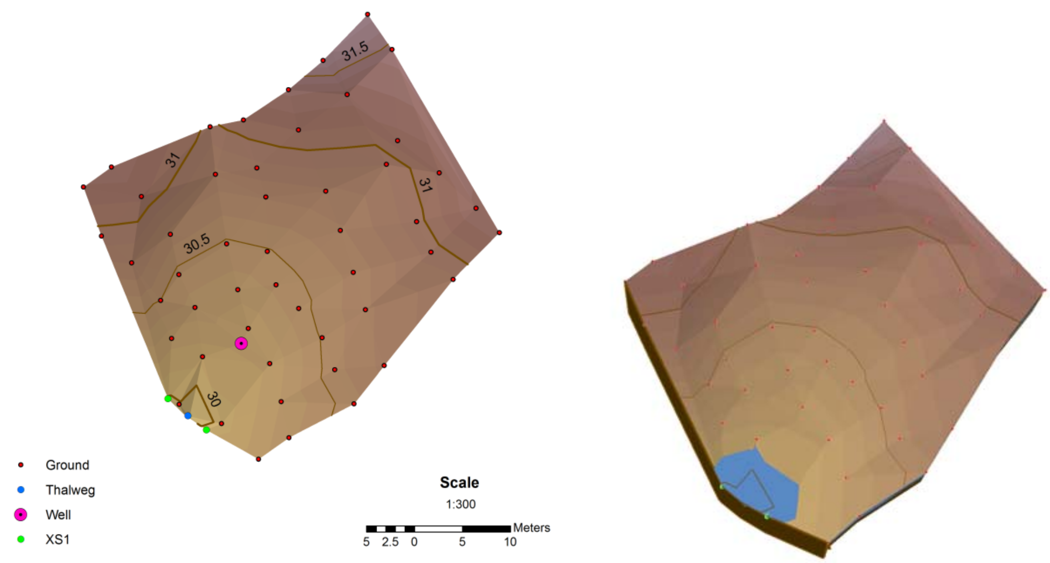


Figure 3.11. Topographic maps for Site 2.
†Present conditions are displayed on the left and potential conditions after restoration are displayed on the right. The pink represents the well (WELL), the green dots represent the permanent benchmarks for cross-section 1 (XS1), the blue dot represents the thalweg (TW) within the cross-section and the red dot represents each point that was surveyed (Ground). The contour lines are in 0.5 meter intervals and do not represent the actual elevation, but rather an elevation relative to the lowest point surveyed on the whole topographic map.

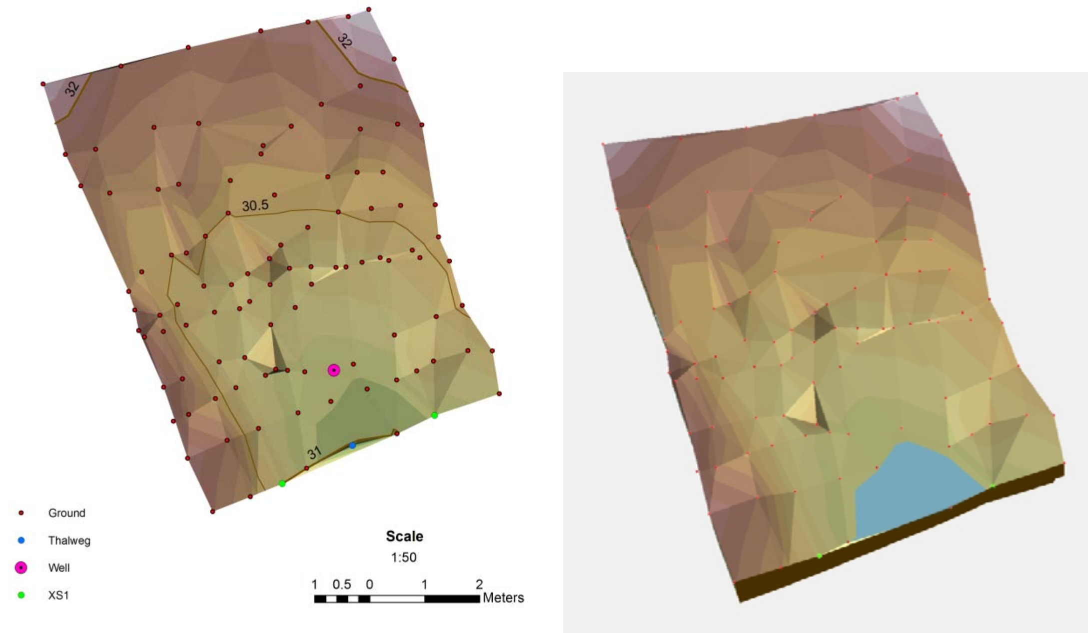


Figure 3.12. Topographic maps for Site 3.
†Present conditions are displayed on the left and potential conditions after restoration are displayed on the right. The pink represents the well (Well), the green dots represent the permanent benchmarks for cross-section 1 (XS1), the blue dot represents the thalweg (TW) within the cross-section and the red dot represents each point that was surveyed (Ground). The contour lines are in 0.5 meter intervals and do not represent the actual elevation, but rather an elevation relative to the lowest point surveyed on the whole topographic map.

A study in Rocky Mountain National Park, Colorado documented the restoration of a mountain fen. The fen had similar hydrology to that of the wetlands at the study area and a drainage ditch that was effectively draining the wetland. Restoration involved blocking the channel with soil, which restored surface sheet flow, anaerobic conditions and high, late-summer water tables in the fen (Cooper et al., 1998). Despite the effectiveness of the project, the effects were temporary because the soil was easily eroded. To avoid the same results at the wetlands in this study, different materials would need to be used. Ideally, the debris dam would be made of natural materials (logs, rocks, soil, and leaf litter), with a layer of soil on top that hosts native plants in order to help control erosion. A debris dam created for a study examining the effects of hyporheic exchange (Hester and Doyle, 2008) can be seen in Figure 3.13. A similar structure could be used for the wetlands of this study.

Figure 3.13. Example of a debris dam used to hold back water in a wetland.

Other wetland restoration projects involving two southern Appalachian floodplains used similar strategies of blocking drainage ditches to increase the water table. The restorations were successful in restoring site hydrology and the authors of both studies stressed the importance of monitoring restoration projects many years following restoration activities (Moorhead et al., 2008; Rossell et al., 2009).

Using the topographic maps, it was possible to determine the effect of a debris dam on the area and volume of the wetland, generated from the stage-storage graphs below (Figures 3.14 – 3.16). The average depth was determined using the following equation: depth = (volume/area).

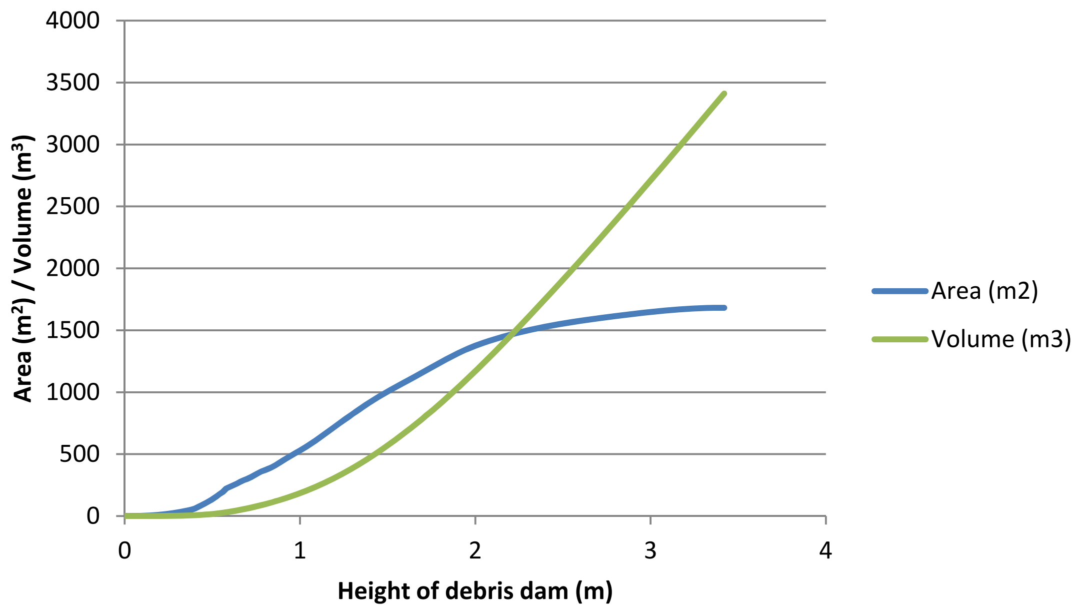


Figure 3.14. Site 1 Stage-Storage Graph.
†The blue line represents the change in area (m^2) as the height of the debris dam increases. The green line represents the change in volume of the wetland (m^3) as the height of the debris dam increases.

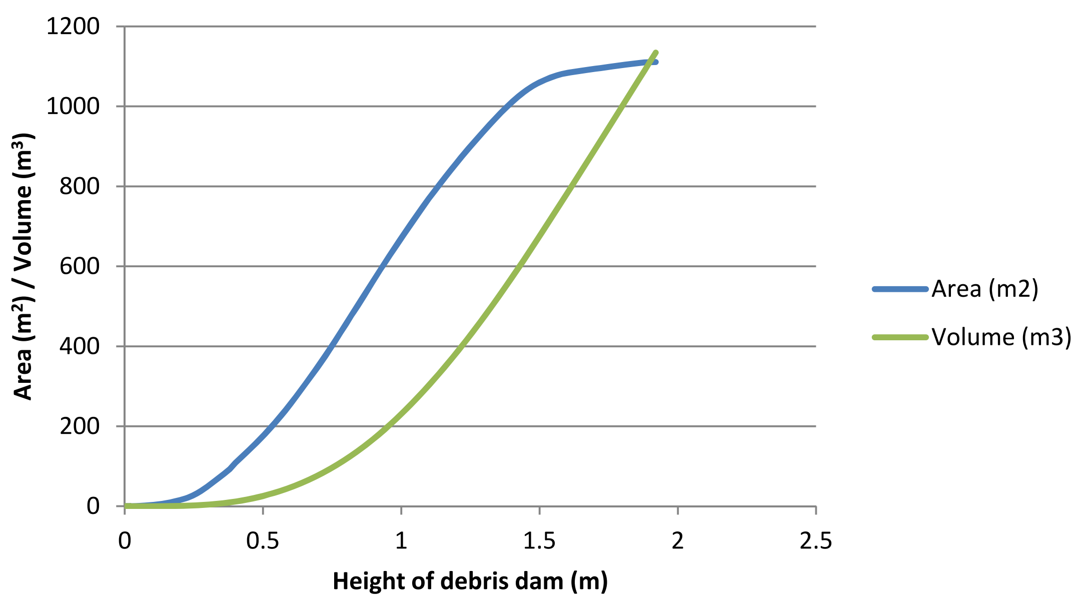


Figure 3.15. Site 2 Stage-Storage Graph.
†The blue line represents the change in area (m^2) as the height of the debris dam increases. The green line represents the change in volume of the wetland (m^3) as the height of the debris dam increases.

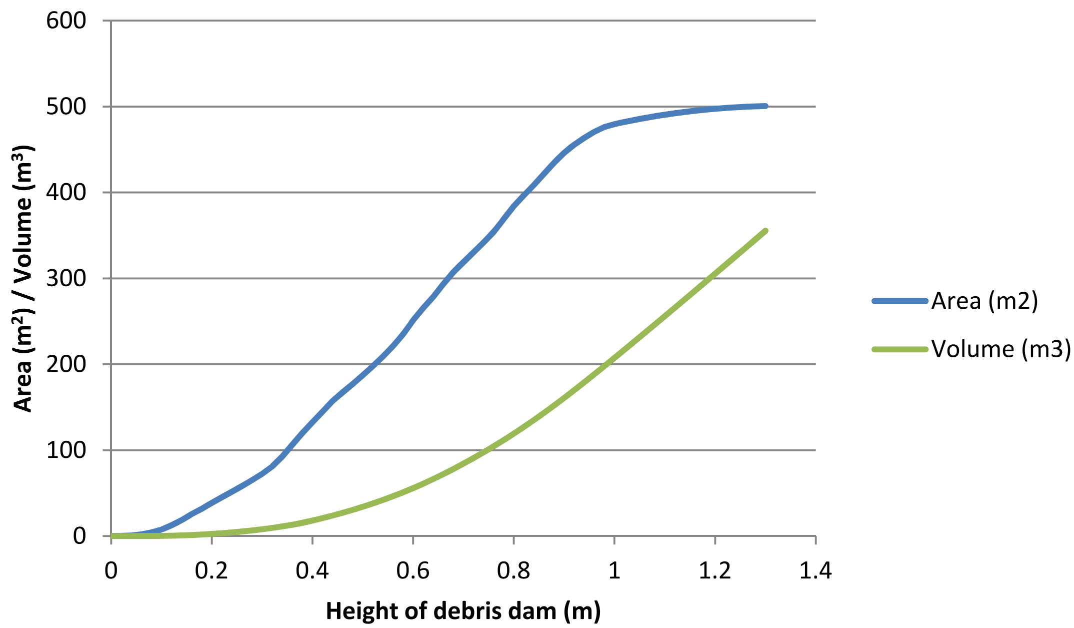


Figure 3.16. Site 3 Stage-Storage Graph.
†The blue line represents the change in area (m^2) as the height of the debris dam increases. The green line represents the change in volume of the wetland (m^3) as the height of the debris dam increases.

To achieve the wetland conditions depicted in the topographic maps above (Figures 3.10 – 3.12) the debris dams would need to be built to a height of 0.62 m for Site 1, 0.26 m at Site 2, and 0.14 m for Site 3. The surface area created from the debris dams would be 248.4 m^2, 31.83 m^2, and 18.82 m^2, for Sites 1, 2, and 3 respectively. The corresponding volumes would be 39.95 m^3, 2.27 m^3, and 0.72 m^3, and the corresponding average depths would be 0.16 m, 0.07 m, and 0.04 m respectively.

It must be noted that the stage-storage graphs show the *expected* change in volume and area with changing height of the debris dam. The actual changes may be different, so it would be necessary to start with a small debris dam and document the results while making gradual adjustments until ideal conditions for the orchids are obtained. Alternatively a stand pipe or water control structure could be installed to help control water table depth. Unfortunately, no data was found regarding the most appropriate water level for *P.integrilabia* and *P.cristata*.

It is imperative that all of the research conducted in this project be continued in the future, especially before and after any management plans are implemented. Several years of hydrologic data are necessary to fully understand the hydrologic regime of a wetland, especially seasonally saturated wetlands, due to their variable hydrology (Karanthasis et al, 2003). Rossell et al. (2009) also emphasized the need for monitoring restored wetlands over long periods to evaluate the effects of restoration.

Chapter 4. CONCLUSION

Although it was originally thought that the wetlands in this study were acidic headwater seeps, the data presented in the previous sections strongly suggests otherwise. The acidic nature of the water in the wetlands is a reflection of acidity in the precipitation; the soils are also acidic which contribute to this misnomer. The results from the hydrologic characterization demonstrate that the wetlands are ombrotrophic, meaning their primary water source is precipitation. This was determined based on the hydrographs, the piezometer manual readings, the isotopic analysis and the water chemistry data. The hydrographs show considerable fluctuations in the water level over the course of a year which suggests a lack of groundwater influence because wetlands that are connected to groundwater systems tend to have less extreme variation in their hydroperiod (Thompson et al., 2007). The piezometer readings reinforce the absence of groundwater in the wetlands because of the tight fit found between the water level in the piezometers and the well throughout the study sites. Because the wetlands do not receive significant water from a groundwater source, a precipitation-fed system is the most reasonable conclusion. The most compelling argument for this conclusion is based on the isotopic analysis of the precipitation and surface water from the wells at each wetland, suggesting that the wetlands are ombrotrophic. This is reinforced by the water chemistry data which is also quite similar to that observed in the precipitation.

A water budget depicts all of the inputs and outputs affecting the hydrology of a wetland. From the water budget graphs, it was found that evapotranspiration accounts for 58% of the water leaving the wetland. The remaining 42% leaves as surface runoff in the channels draining the wetland. Channel cross-sections from 2010 and 2011 did not suggest an overall trend of incision or aggregation, suggesting that the channels are currently stable.

The soils and tensiometer data verify the presence of a restrictive layer in the soil. A Bxg horizon in the soil was found between 10 cm and 30 cm at each site, which is likely responsible for the perched water table. In addition, the soil moisture graphs show a split between the 30 cm and 60 cm tensiometers at each site. This has been seen in other studies and is indicative of a restrictive layer in the soil (Karathanasis et al., 2003). The restrictive layer found in the soils at the study area plays a major role in the existence of the wetlands. It prevents water from draining through the soil, which gives the wetlands their unique hydrologic, edaphic and vegetative characteristics.

Mountain wetlands in southern Appalachia are few and far between. Traditionally they have been referred to as bogs and fens (Weakley and Schafale, 1994), but it is now understood that there are several different types and it is important to understand those distinctions. The wetlands at the study area are similar to each other in several ways; they share similar hydroperiods, soils, topography and water chemistry. This similarity among the sites is helpful and important for future research and management.

Other wetlands where *P.integrilabia* and *P.cristata* can be found have been described as slightly acidic, partially shaded bogs in southern Appalachia ranging in elevation from 300 m to 740 m (Zettler and Fairey, 1990; Zettler and McInnis 1994; Zettler et al., 1996 (a); Zettler and Hofer, 1998). The wetlands in this study could be considered more than partially shaded, which indicates that hydrology might not be the sole reason for the decline in the number of orchids. It will be necessary to explore the light requirements of *P.integrilabia* and *P.cristata* in order to manage for their needs and maintain the populations.

Management recommendations for the wetlands involve reduction of the wetlands basal area through thinning and the restoration of wetland hydrology through the construction of debris dams in the channels exiting the wetlands. These activities will increase light availability to the orchids, increase surface area and volume in the wetlands as well as extend the duration of saturation. Figure 3.6 will be helpful in decisions regarding the amount of thinning that needs to occur and the effect it will have on the hydrology of the wetland. The topographic maps (Figure 3.10 – 3.12) and the stage-storage graphs (Figure 3.14 – 3.16) can be used as a reference for building debris dams in the channels exiting the wetlands. If necessary, gradual adjustments can be made to the height of the debris dam, depending on the response of the wetland. This must be done carefully and over time, while documenting changes in wetland hydrology, until the most appropriate conditions are created for the wetlands. By building the debris dams, potential channel incision from the thinning (causing increased water yield and stream flow) can be avoided. Because there is no data currently available regarding the hydrologic requirements of the orchids, it may be worthwhile to initiate a greenhouse study using other species of *Platanthera* to determine the optimum hydroperiod and light requirements for that genus.

APPENDIX 1. Channel Cross-Section Summary

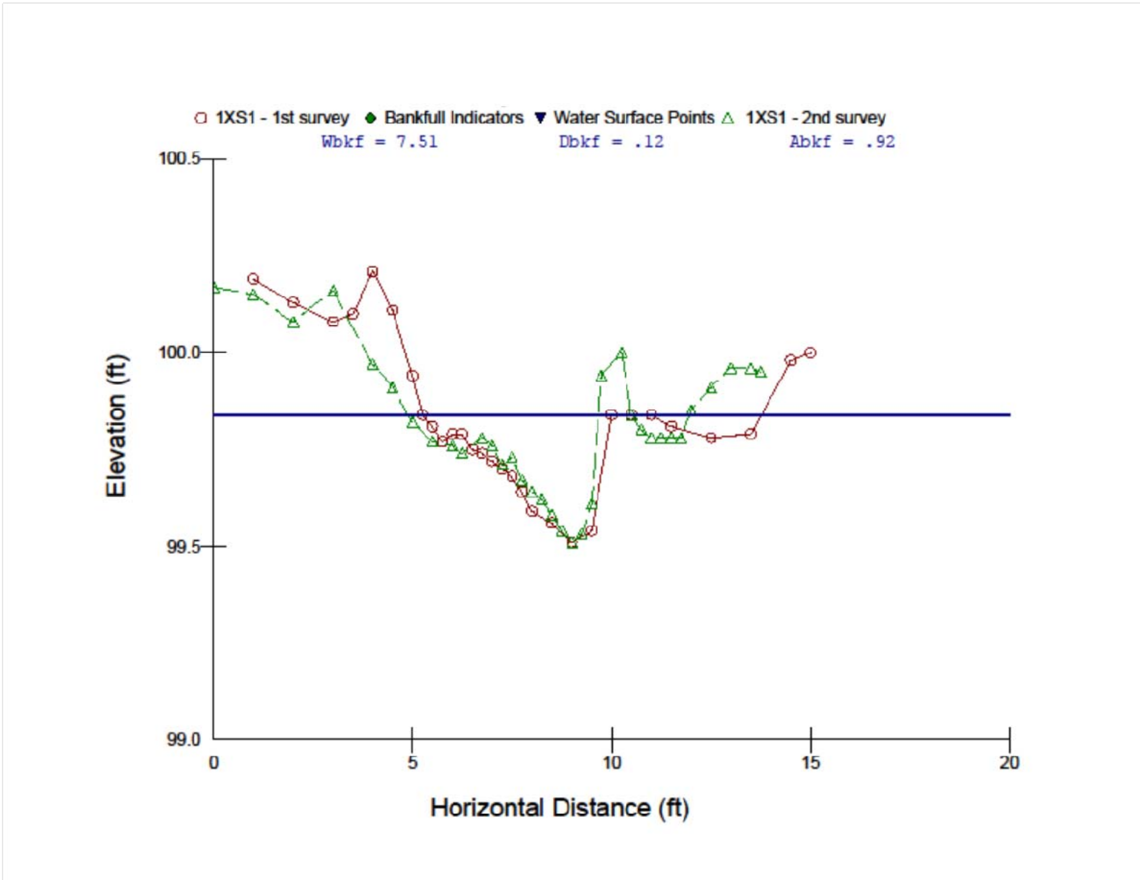
	BKF Width (ft)	Entrenchment Ratio	Mean Depth (ft)	Max Depth (ft)	Width / Depth Ratio	BKF Area (ft^2)	Δ (ft^2)
Site 1 XS1	7.51	0.76	0.12	0.33	62.58	0.92	-0.14
Site 1 XS2	11.1	1.4	0.34	0.84	32.65	3.78	-0.83
Site 1 XS3	4.92	2.39	0.14	0.44	35.14	0.66	-0.07
Site 1 XS4	3.69	3.12	0.32	0.62	11.53	1.18	0.27
Site 1 XS5	5.71	0.08	0.21	0.36	27.19	1.21	0.01
Site 2 XS1	7.25	2.27	0.18	0.32	40.28	1.28	-0.07
Site 2 XS2	5.6	2.01	0.13	0.36	43.08	0.73	0.26
Site 2 XS3	2.75	1.73	0.15	0.3	18.33	0.43	0.03
Site 2 XS4	1.58	3.53	0.09	0.21	17.56	0.15	0.02
Site 2 XS5	5.92	1.66	0.27	0.67	21.93	1.57	0.43
Site 2 XS6	6.25	1.77	0.24	0.6	26.04	1.47	0.18
Site 2 XS7	4.39	2.04	0.35	0.69	12.54	1.55	0.01
Site 2 XS8	4.45	2.45	0.26	0.59	17.12	1.16	0.07
Site 3 XS5	2.81	2.95	0.32	0.57	8.78	0.9	0.21
Site 3 XS6	5.94	2.47	0.19	0.5	31.26	1.14	-0.06
Site 3 XS7	3.46	2.89	0.19	0.49	18.21	0.65	0.04
Site 3 XS8	8.16	1.59	0.12	0.37	68	1	-0.18

APPENDIX 1. Channel Cross-Section Summary cont…

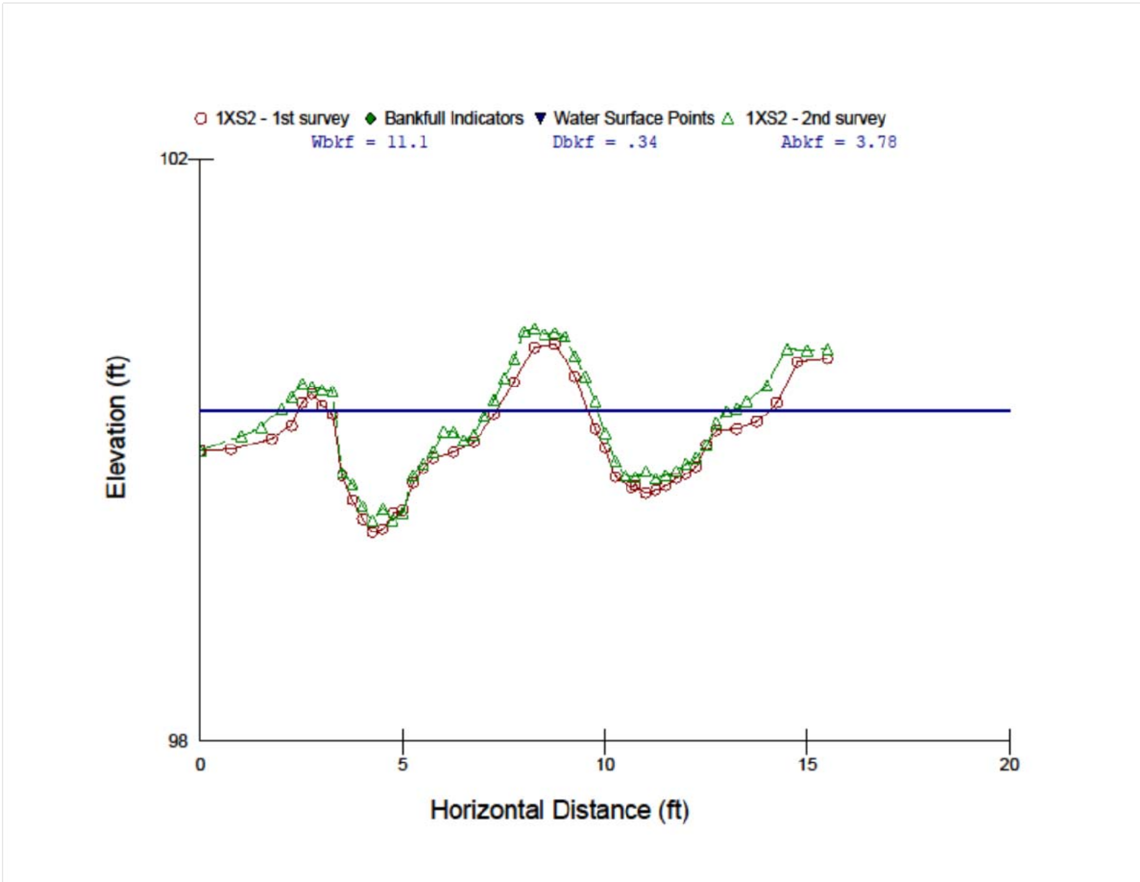
	BKF Width (ft)	Entrenchment Ratio	Mean Depth (ft)	Max Depth (ft)	Width / Depth Ratio	BKF Area (ft^2)	Δ (ft^2)
Site 3 XS9	5.59	2.33	0.16	0.26	34.94	0.89	0.02
Site 3 XS10	4.74	2.99	0.68	1.13	6.97	3.23	0.31

APPENDIX 2. CROSS-SECTION SURVEYS

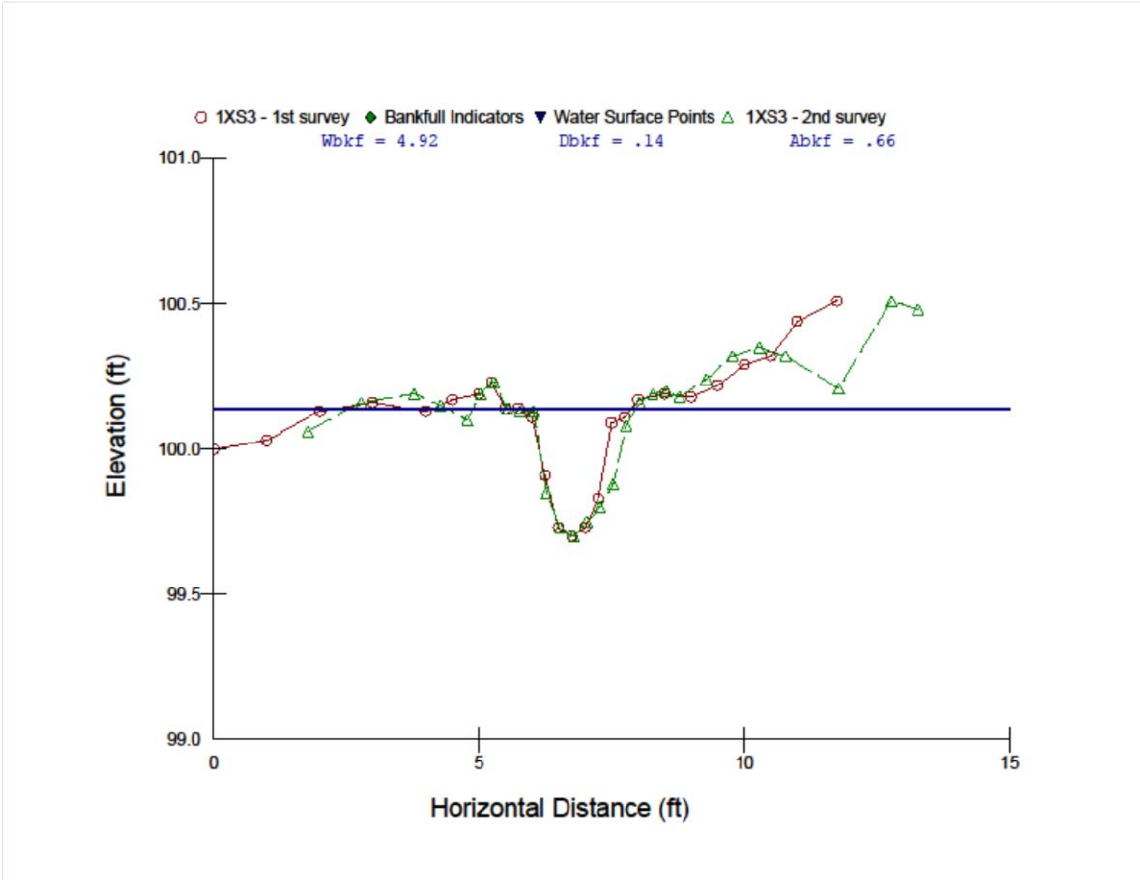
Appendix 2.A. Site 1, Cross-Section 1



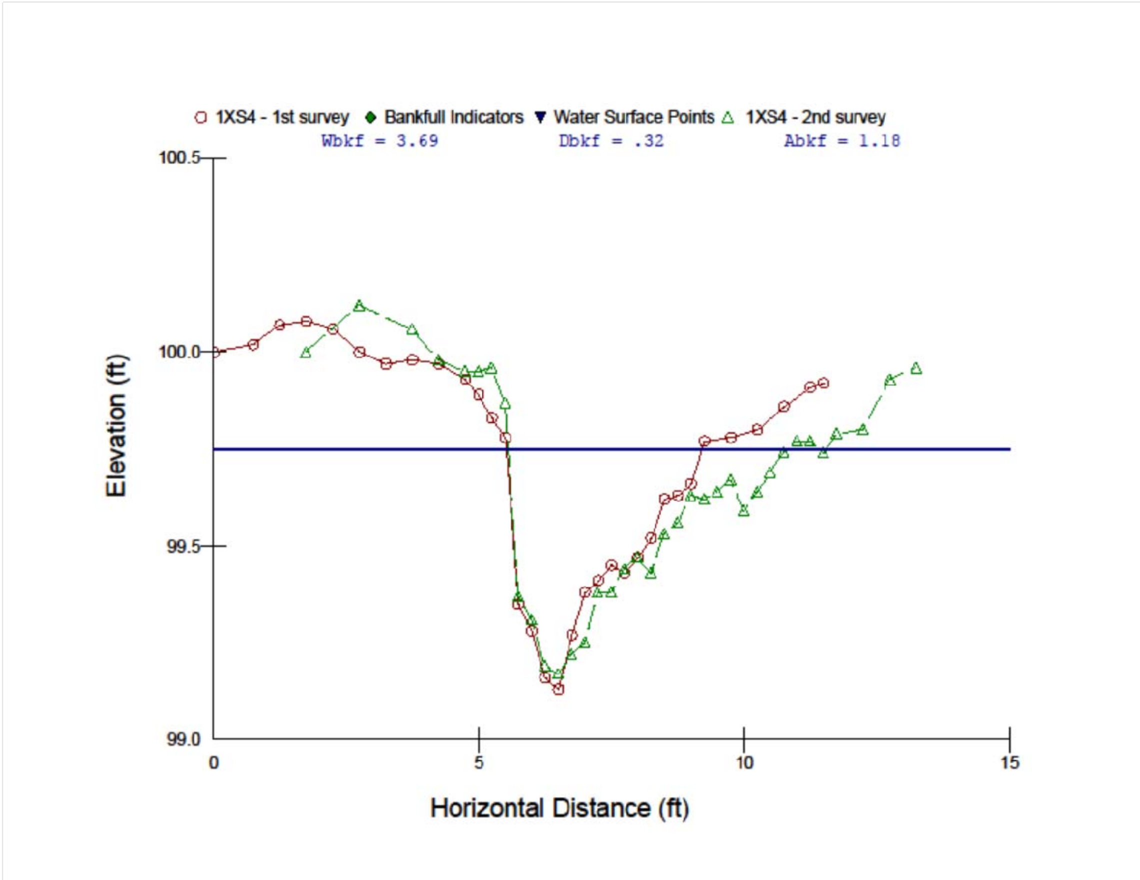
Appendix 2.B. Site 1, Cross-Section 2



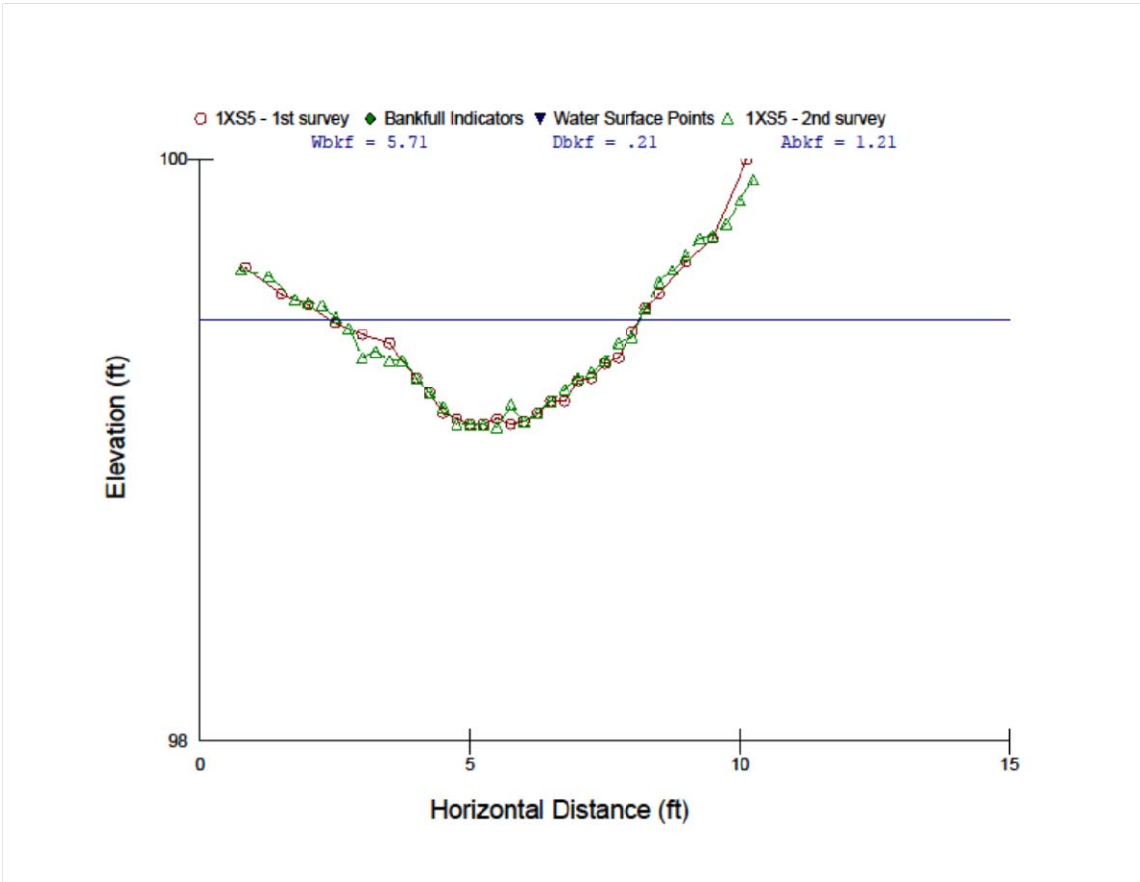
Appendix 2.C. Site 1, Cross-Section 3



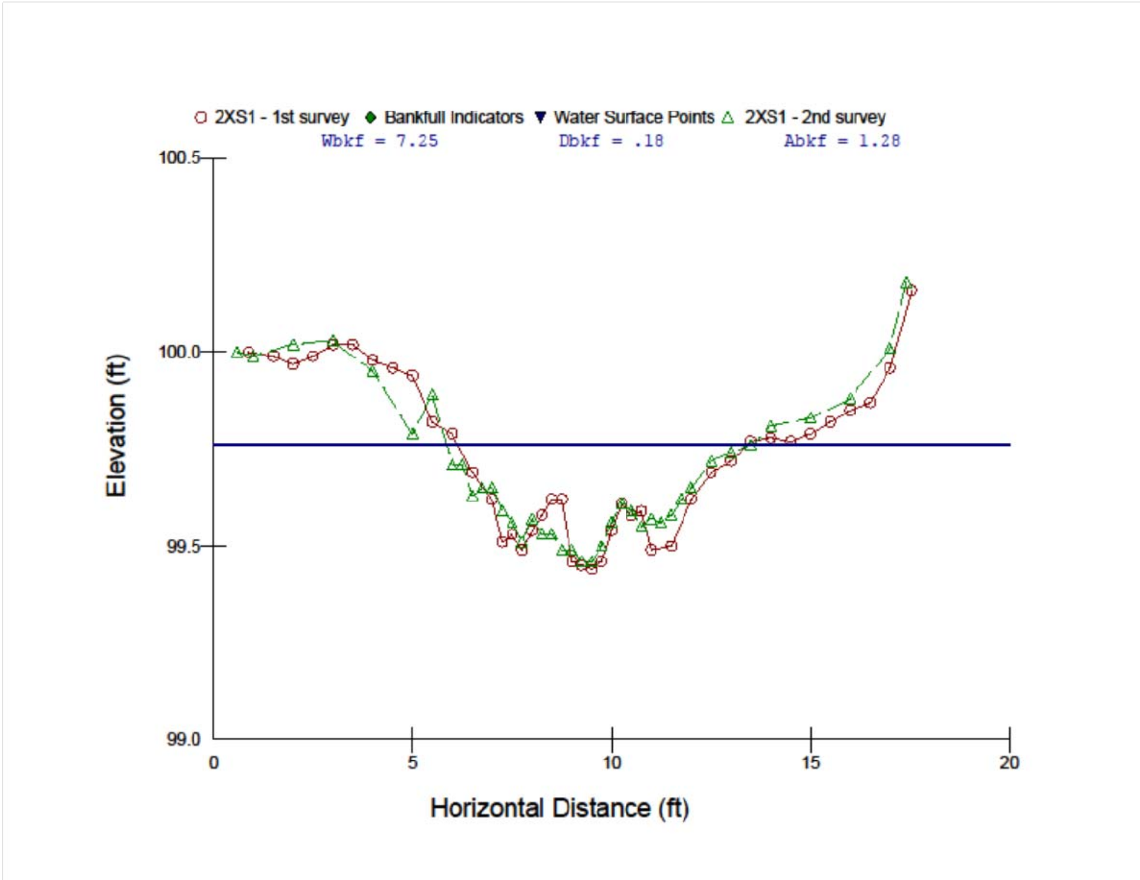
Appendix 2.D. Site 1, Cross-Section 4



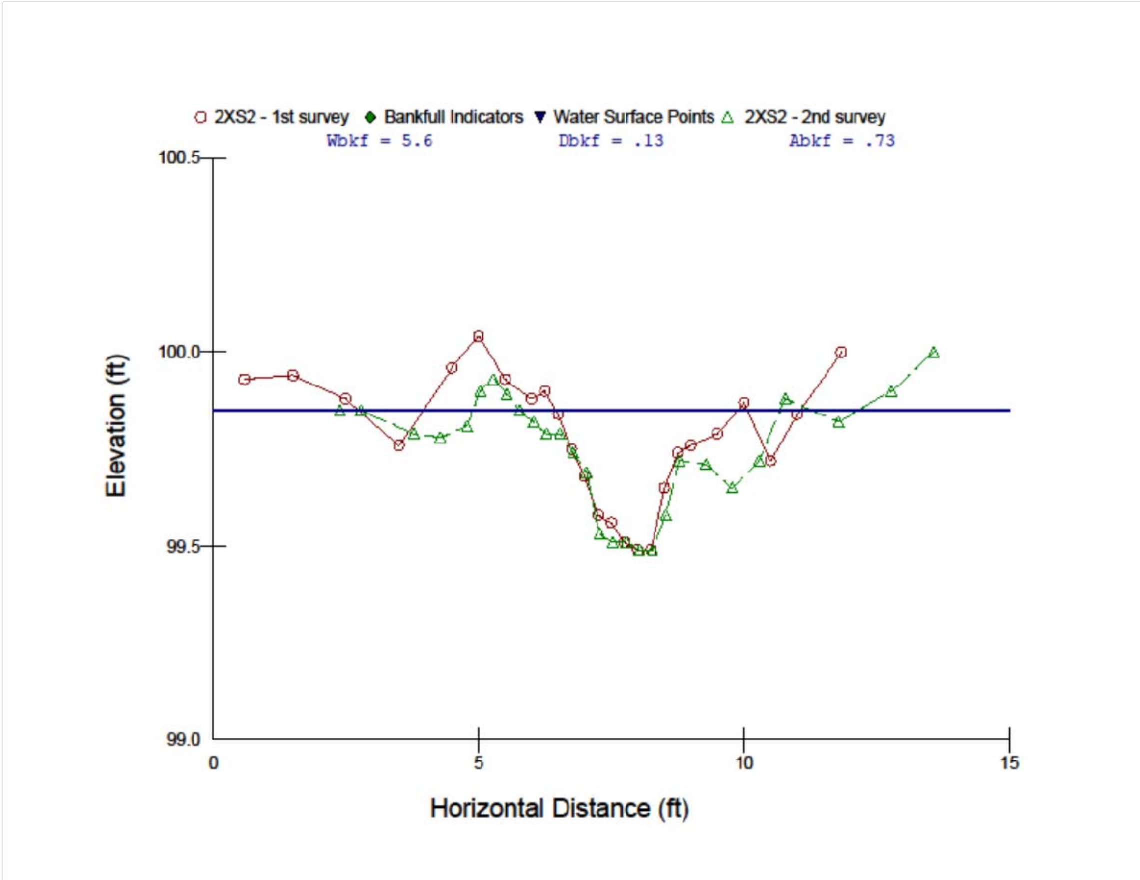
Appendix 2.E. Site 1, Cross-Section 5



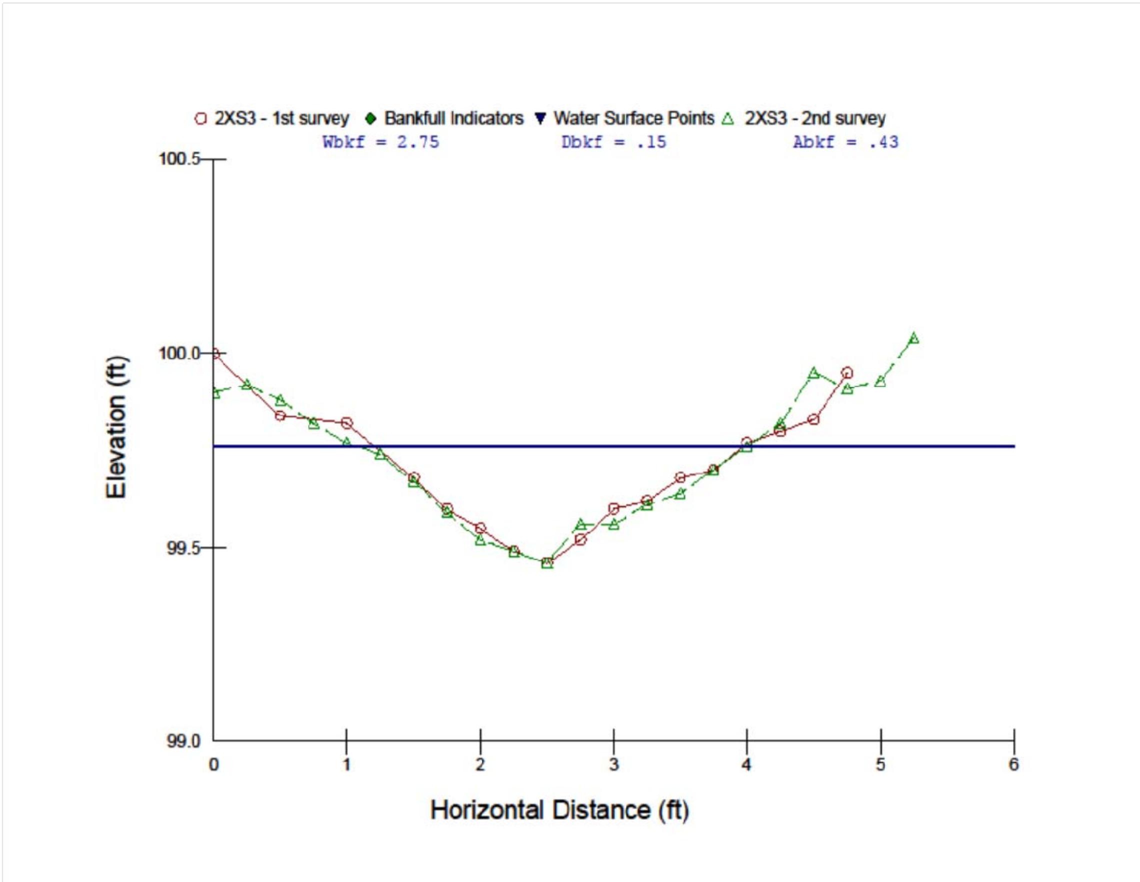
Appendix 2.F. Site 2, Cross-Section 1



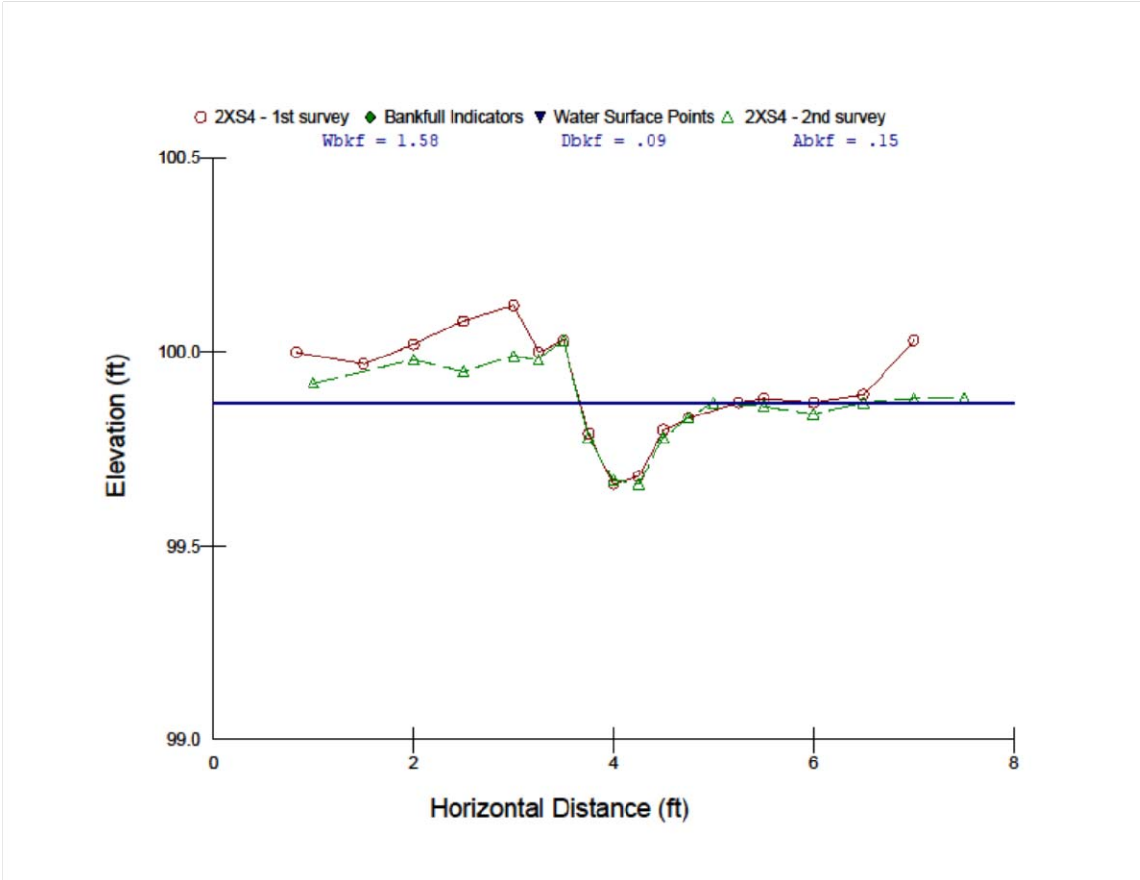
Appendix 2.G. Site 2, Cross-Section 2



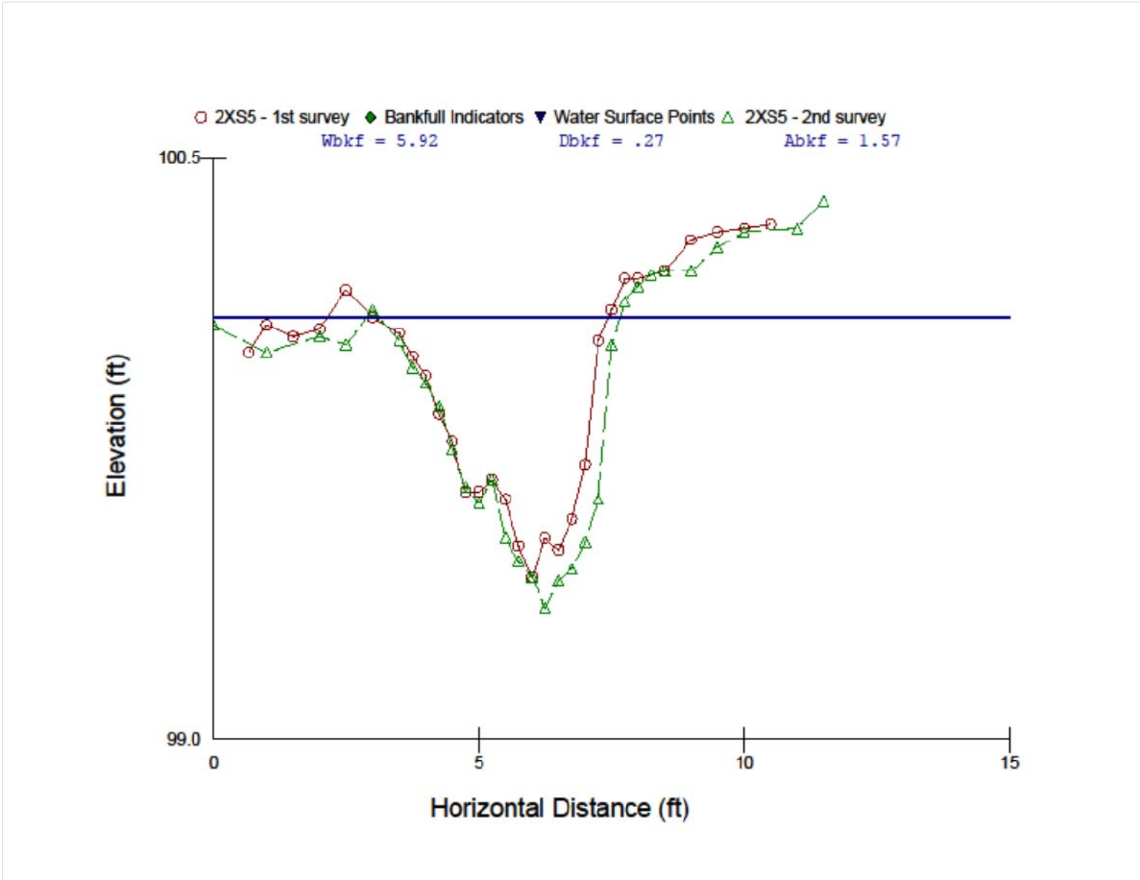
Appendix 2.H. Site 2, Cross-Section 3



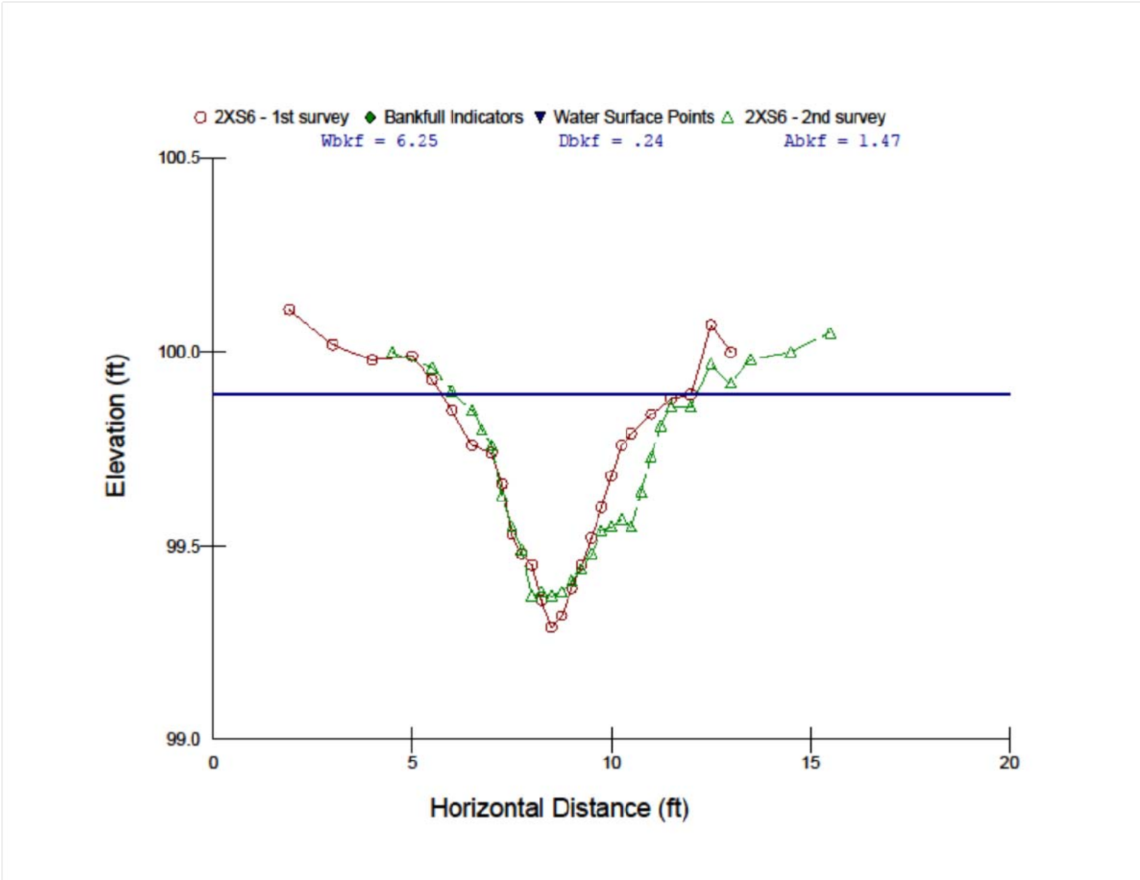
Appendix 2.I. Site 2, Cross-Section 4



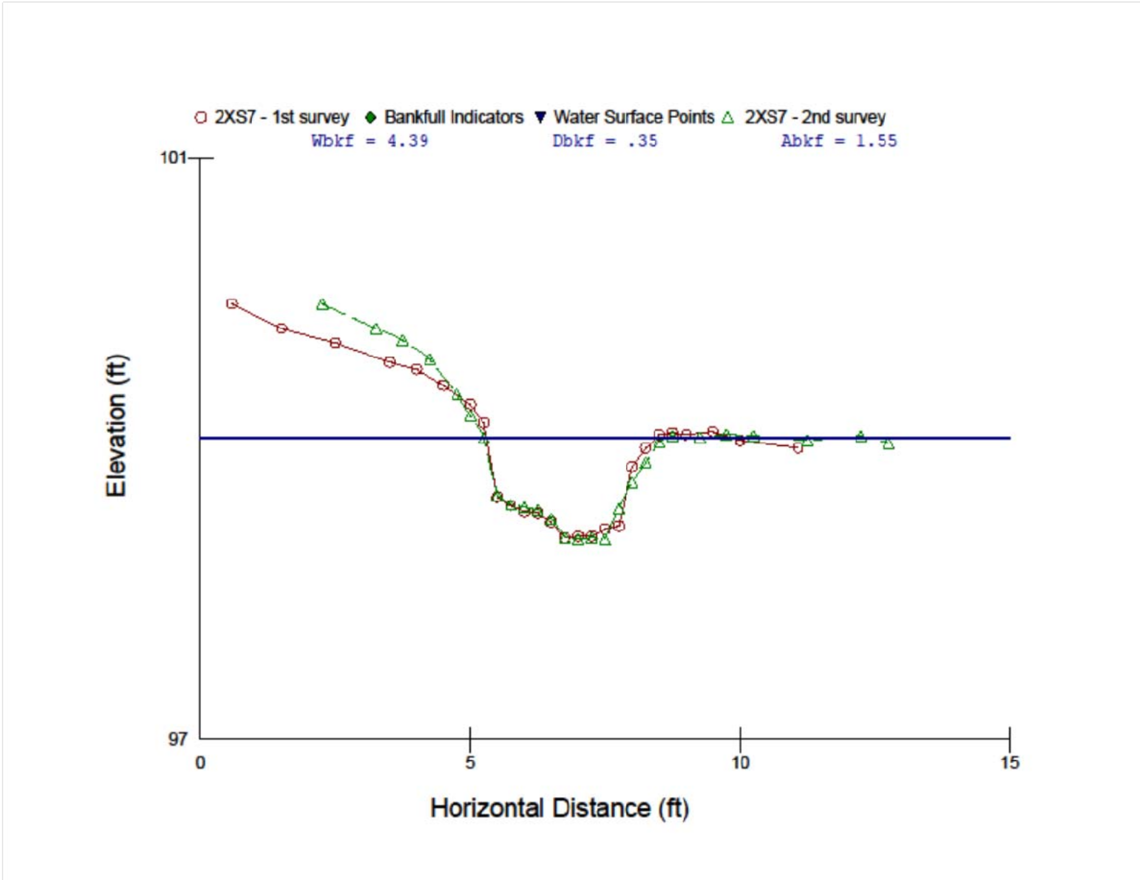
Appendix 2.J. Site 2, Cross-Section 5



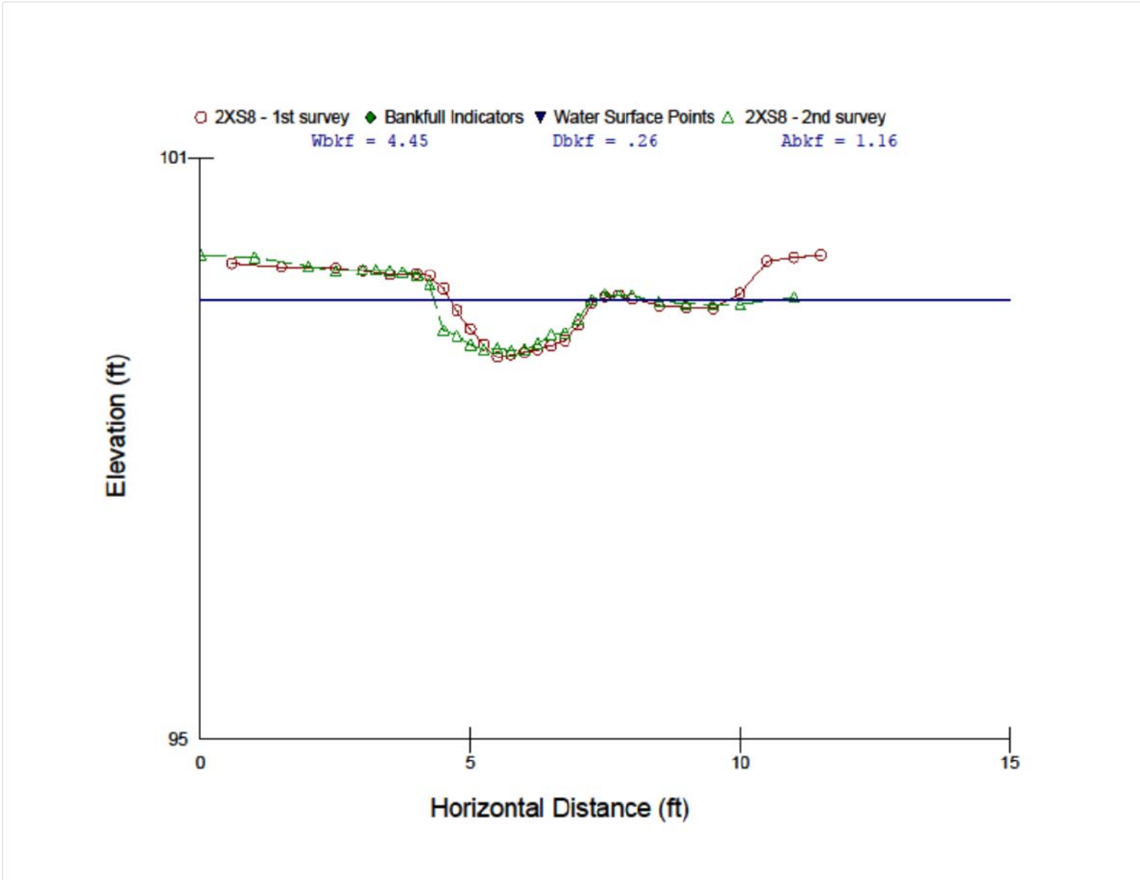
Appendix 2.K. Site 2, Cross-Section 6



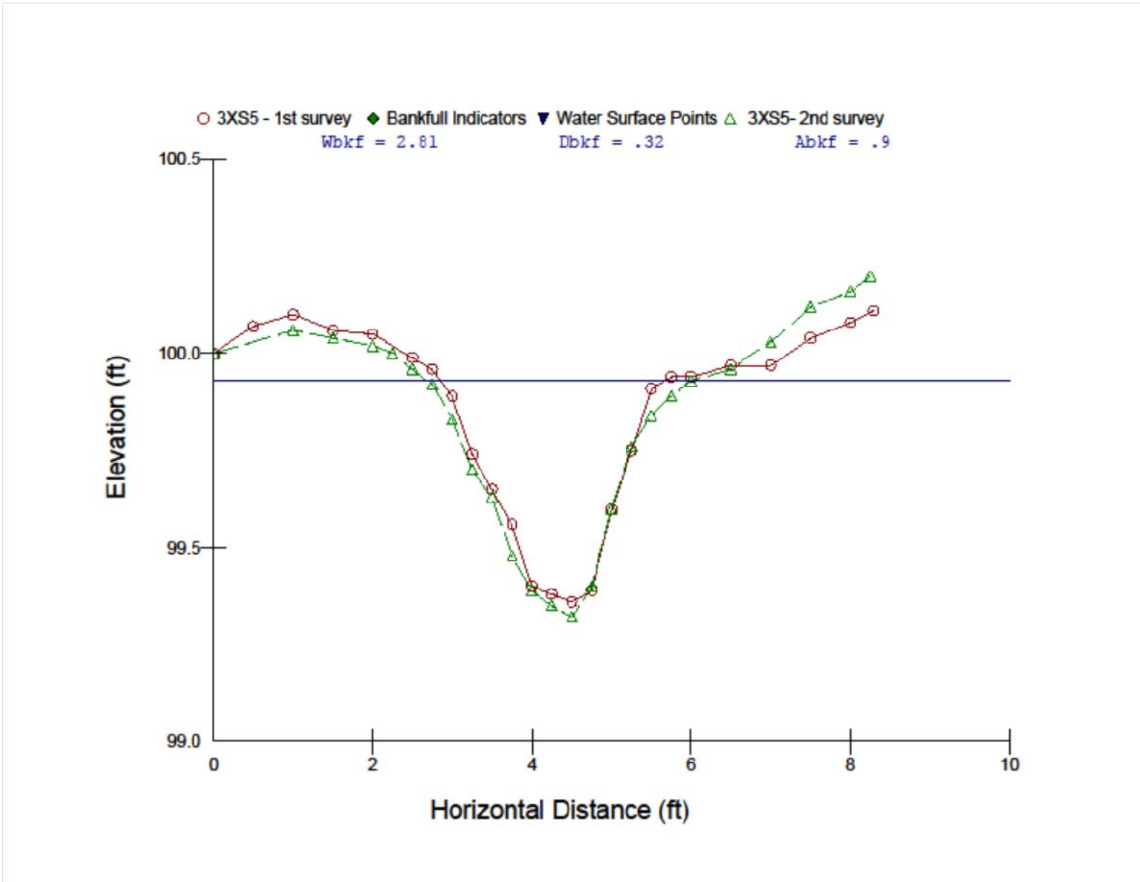
Appendix 2.L. Site 2, Cross-Section 7



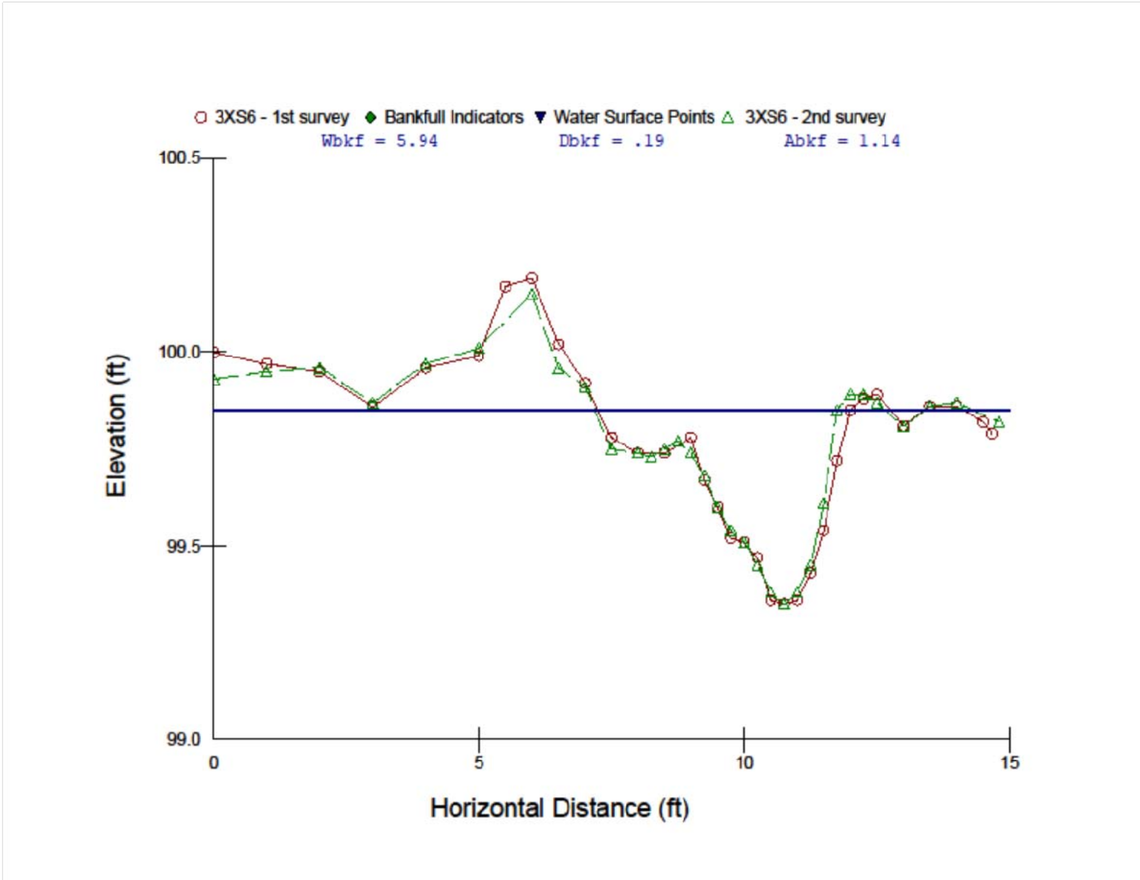
Appendix 2.M. Site 2, Cross-Section 8



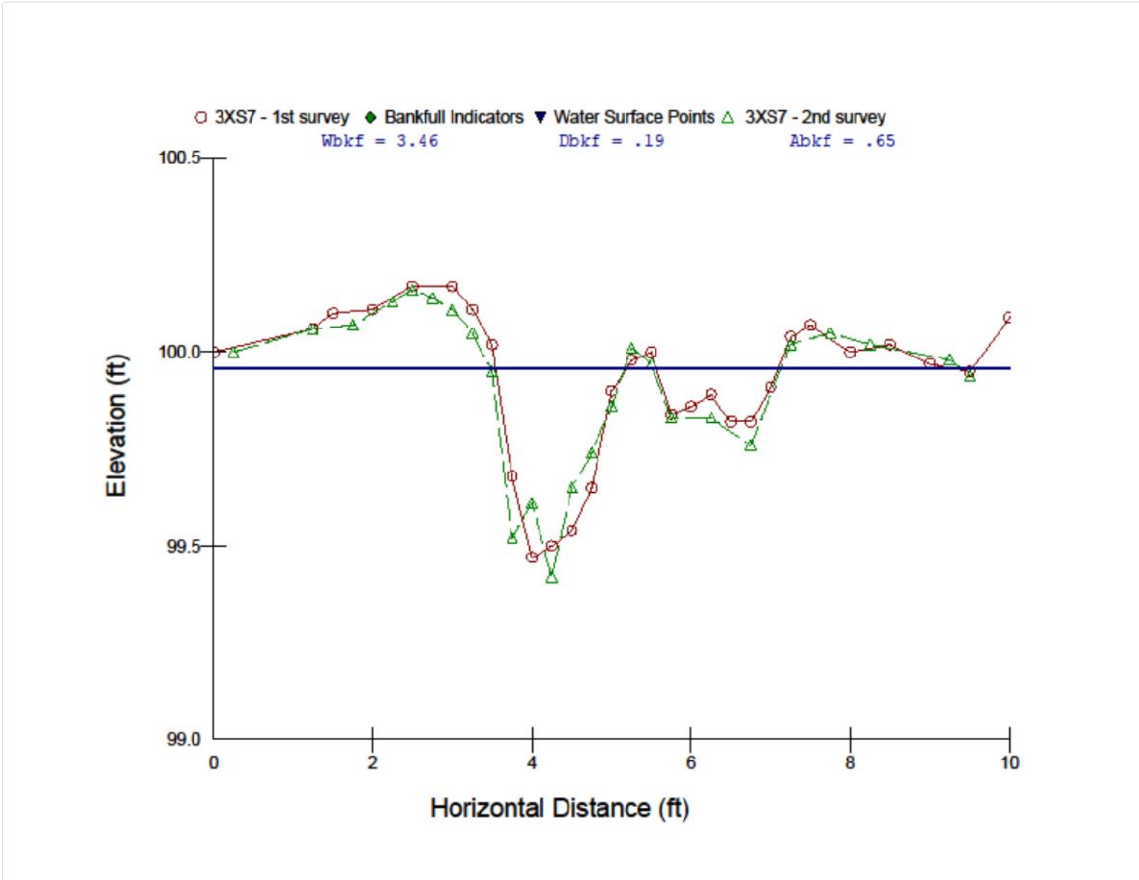
Appendix 2.N. Site 3, Cross-Section 5



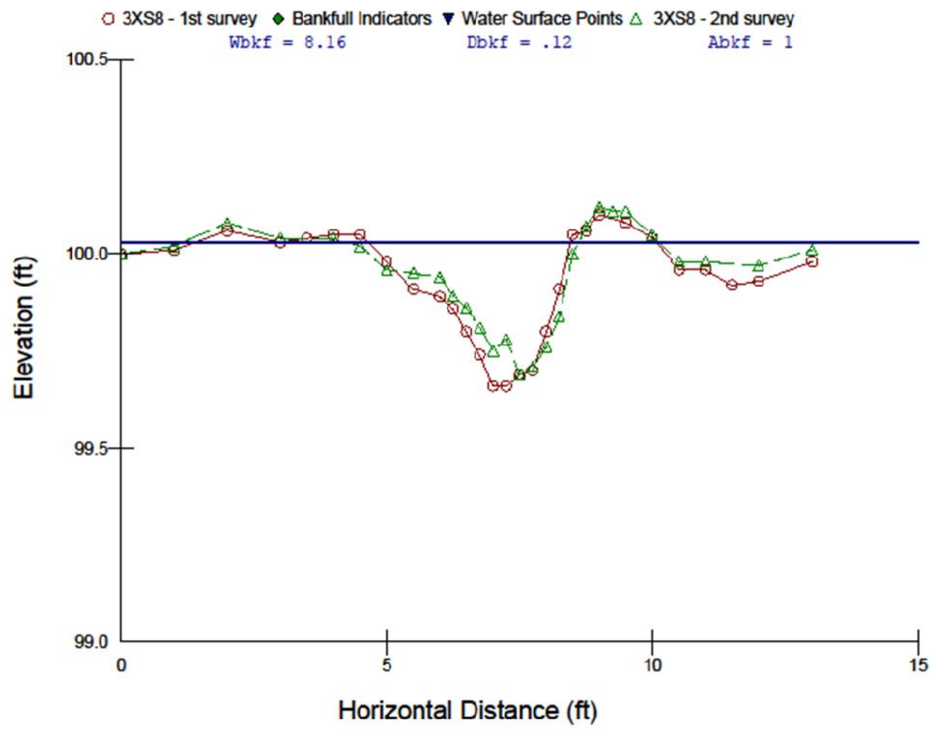
Appendix 2.O. Site 3, Cross-Section 6



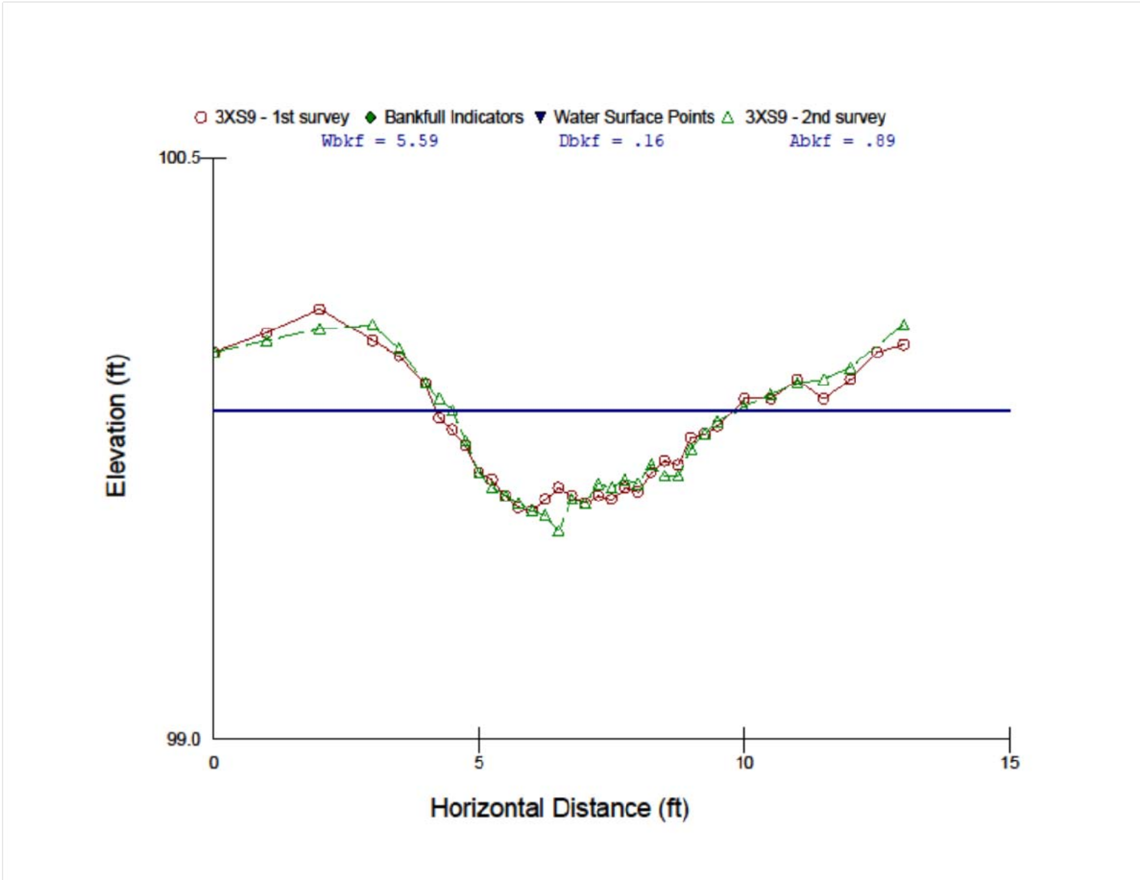
Appendix 2.P. Site 3, Cross-Section 7



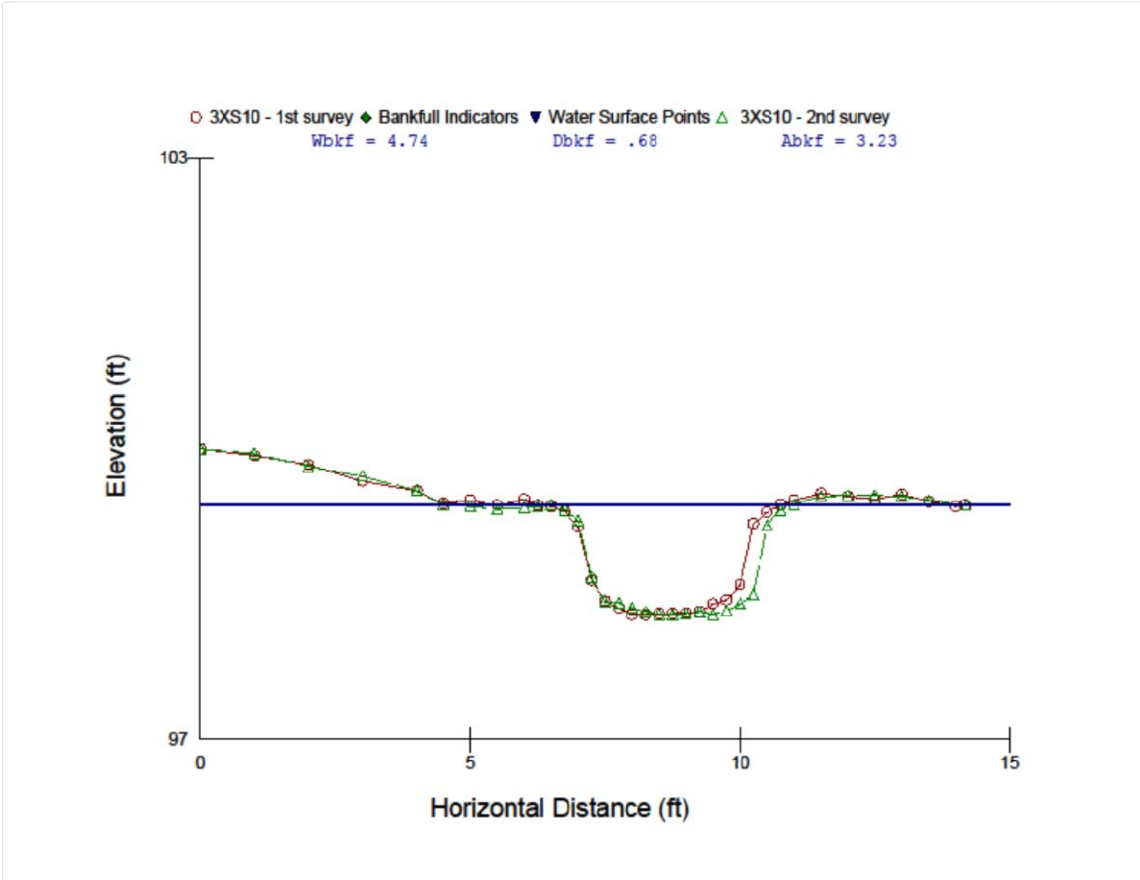
Appendix 2.Q. Site 3, Cross-Section 8



Appendix 2.R. Site 3, Cross-Section 9



Appendix 2.S. Site 3, Cross-Section 10



BIBLIOGRAPHY/REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998) Crop Evapotranspiration Guidelines for Computing Crop Water Requirements. FAO Irrig. and Drain. Paper 56. Food and Agriculture Organization of the United Nations, Rome. pp. 300.

Amataya, D.M., D.F. Joyner, R.W. Skaggs and J. W. Gilliam (2006) Hydrological and Water Quality Effects of Thinning a Drained Pine Plantation in Coastal North Carolina. In: Amataya, Devendra and Jami Nettles (eds) Hydrology and Management of Forested Wetlands: Proceedings of the International Conference, American Society of Agricultural and Biological Engineers, St. Joseph, Michigan, pp. 483. (a)

Amataya, D.M., R.W. Skaggs, C.D. Blanton and J.W. Gilliam (2006) Hydrologic and Water Quality Effects of Harvesting and Regeneration of a Drained Pine Forest. In: Amataya, Devendra and Jami Nettles (eds) Hydrology and Management of Forested Wetlands: Proceedings of the International Conference, American Society of Agricultural and Biological Engineers, St. Joseph, Michigan, pp. 538-551. (b)

Ayalon, A., M. Bar-Matthews, and E. Sass (1997) Rainfall-Recharge Relationships Within a Karstic Terrain in the Eastern Mediterranean Semi-Arid Region, Israel: δO^{18} and δD characteristics. Journal of Hydrology 207:18-31

Barackman, M. and M.L. Brusseau (2004) Groundwater Sampling. In: Artiola, Janick F., Ian L. Pepper and Mark L. Brusseau (ed) Environmental Monitoring and Characterization,1st edn. Elsevier, New York, pp1-9.

Barton, C. D., D.M. Andrews, and R.K. Kolka (2008) Evaluating Hydroperiod Response in Restored Carolina Bay Wetlands Using Soil Physicochemical Properties. Restoration Ecology 16:668-677.

Batzer, D.P. and R.R. Sharitz (2006) An Introduction. In: Batzer, Darold P.and Rebecca R. Sharitz (ed) Ecology of Freshwater and Estuarine Wetlands,1st edn. University of California Press, Berkley, California pp1-5.

Brooks, R., and M. Hayashi (2002) Depth-Area-Volume and Hydroperiod Relationships of Ephemeral (Vernal) Forest Pools in Southern New England. *Wetlands* 22:247-255.

Carriera, P. M. et al. (2011) Defining the Dynamics of Groundwater in Serra de Estrela Mountain Area, Central Portugal; An Isotopic and Hydrogeochemical approach. Hydrogeology Journal 19:117-131.

Chagué-Goff, C., A.F. Mark, and K.J. M. Dickinson (2010) Hydrological Processes and Chemical Characteristics of Low-Alpine Patterned Wetlands, South-Central New Zealand. Journal of Hydrology 385:105-119.

Chen, J.M. and T.A. Black (1992) Defining leaf-area indesc for non-flate leaves. Plant Cell and Environment 15: 421-429.

Chowdhury, N., P. Marschner, and R. Burns (2011) Response of Microbial Activity and Community Structure to Decreasing Soil Osmotic and Matric Potential. Plant and Soil 344:241-54.

Collins, M. E., and R.J. Kuehl (2001) Organic Matter Accumulation and Organic Soils. In: Richardson, J.L. and M.J. Vepraskas. Wetland Soils: Genesis, Hydrology, Landscapes and Classification, 1st edn. Lewis Publishers, Boca Raton, Florida, pp 137-162.

Cooper, D., et al. (1998) Hydrologic Restoration of a Fen in Rocky Mountain National Park, Colorado, USA. Wetlands 18:335-345.

Currah, R.S., L.W. Zettler, and T.M. McInnis (1997) *Epulorhiza inquilina* sp. nov. from *Platanthera* (Orchidaceae) and a Key to *Epulorhiza* Species. Mycotaxon 61:335-341.

DeSteven, D. (1991) Experiments on Mechanisms of Tree Establishment in Old-Field Succession: Seedling Emergence. 72: 1066-1075.

DeWalle, D.R., P.J. Edwards, B.R. Swistock, R. Aravena and R.J.Drimmie (1997) Seasonal Isotope Hydrology of Three Appalachian Forest Catchments. Hydrological Processes 11:1895-1906.

Entry, J.A., B.G. Lockaby, J.D. Hodges, S.H. Schoenholtz, J.A. Stanturf, and E.S. Gardner. (1995) Influence of Hydroperiod on Function and Structure of Forested Wetland Ecosystems. In: K.L. Campbell (ed.) Versatility of Wetlands in the Agricultural Landscape. American Society of Agricultural Engineers. p 723-734.

Ernst, J.P., and V. Brown (1989) Conserving Endangered Species on Southern Forested Wetlands. In: Mistch, William J. and James G. Gosselink. Wetlands (1993).

Evangelou, V.P. (1998) Environmental Soil and Water Chemistry: Principles and Applications. New York.

Francl, K. E., W. Mark Ford, and S. B. Castleberry (2004) Characterization of High Elevation Central Appalachian Wetlands. United States Department of Agriculture Forest Service Research Paper. NE-725. 30pp.

Fontes, J.C. (1980) Environmental Isotopes in Groundwater Hydrology. In: Fritz, P. and J.C. Fontes (eds) Handbook of Environmental Isotope Geochemistry. Elsevier, Amsterdam, pp 75-134.

Greenberg, A.E., et al. (1992) Standard Methods for the Examination of Water and Wastewater. American Public Health Association.

Hall, B., D. Raynal, and D. Leopold (2001) Environmental Influences on Plant Species Composition in Ground-Water Seeps in the Catskill Mountains of New York. Wetlands 21:125-134.

Hendricks, D.M. (2004) Maps in Environmental Monitoring. In: Artiola, Janick F., Ian L. Pepper and Mark L. Brusseau (ed) Ecology of Freshwater and Estuarine Wetlands,1st edn. Elsevier, New York, pp 69-84.

Henderson, A.K., D.M. Nelson, F.S. Hu, Y. Huang, B.N. Shuman, J.W. Williams (2010) Holocene Precipitation Seasonality Captured by a Dual Hydrogen and Oxygen Isotope Approach at Steel Lake, Minnesota 300: 205-214.

Hester, E. T. and M.W. Doyle (2008) In Stream Geomorphic Structures as Drivers of Hyporheic Exchange. Water Resource Journal 44:1-17.

Hillel, D. (1998) Environmental Soil Physics. San Diego, California.

Hulsmans, A., et al. (2008) Quantifying the Hydroregime of a Temporary Pool Habitat: A Modelling Approach for Ephemeral Rock Pools in Se Botswana. Ecosystems 11:89-100.

Hurt, G.W., and V.W. Carlisle (2001) Delineating Hydric Soils. In: Richardson, J.L. and M.J. Vepraskas. Wetland Soils: Genesis, Hydrology, Landscapes and Classification, 1st edn. Lewis Publishers, Boca Raton, Florida, pp 183-208.

Itenfisu, D., R.L. Elliot, R.G. Allen and I.A. Walter (2000) Comparison of Reference Evapotranspiration Calculations across a Range of Climates. Proc. of the National Irrigation Symposium, November 2000, Phoenix, AZ, American Society of Civil Engineers, Environmental and Water Resources Institute, New York, NY.

Karathanasis, A. D., Y. L. Thompson, and C. D. Barton (2003) Long-Term Evaluations of Seasonally Saturated "Wetlands" in Western Kentucky. Soil Science Society of America Journal 67:662-673.

Kentucky State Nature Preserves Commission (2011) Rare and Extirpated Biota and Natural Communities of Kentucky. Unpublished.

Kolka, R.K. and J.A. Thompson (2006) Wetland Geomorphology, Soils, and Formative Processes. In: Batzer, Darold P. and Rebecca R. Sharitz (ed) Ecology of Freshwater and Estuarine Wetlands,1st edn. University of California Press, Berkley, California pp7-41.

Korfel, C.A., W.J. Mitsch, T. E. Hetherington and J. J. Mack. (2010) Hydrology, Physiochemistry and Amphibians in Natural and Created Vernal Pool Wetlands. Resotration Ecology 18: 843-854.

Lee, D.R. and J.A. Cherry. (1978) A Field Exercise on Groundwater Flow Using Seepage Meters and Mini-Piezometers. Journal of Geological Education 27:6-10.

Leudeling, E. and Andreas Buerkert. (2008) Effects of Land Use Changes on the Hydrologic Sustainability of Mountain Oases in Northern Oman. Plant and Soil 304:1-20.

Lloyd, J.W., and J.A. Heathcote (1985) *Natural Inorganic Hydrochemistry in Relation to Ground Water*. From Review by Thomas R. Wildeman, Colorado School of Mines In: Journal of the American Chemical Society 109: 1-296.

Martin and Kirkman. (2009) Management of Ecological Thresholds to Re-establish Disturbance Maintained Herbaceous Wetlands of the Southeastern, USA. Journal of Applied Ecology 46:906-914.

Matheney, R.K. and P.J. Gerla. (1996) Environmental isotopic evidence for the origin of ground and surface water in a prairie discharge wetland. Wetlands 16: 109-120.

Maurin, L. P. and A. P. Stubblefield (2011) Channel Adjustment Following Culvert Removal from Forest Roads in Northern California, USA. Ecological Restoration 29:382-391.

Mistch, W. J. and J.G. Gosselink. (1993) Wetlands. New York, New York.

Monteith, J.L. (1965) Evaporation and the environment. 205-234. In the movement of water in living organisms, XIXth Symposium. Society of Experimental Biology, Swansea, Cambridge University Press.

Moorhead, K. (2003) Effects of Drought on the Water-Table Dynamics of a Southern Appalachian Mountain Floodplain and Associated Fen. Wetlands 23:792-799.

Moorhead, K., D.Bell, and R.Thorn (2008) Floodplain Hydrology after Restoration of a Southern Appalachian Mountain Stream. Wetlands 28:632-639.

Moorhead, K. K. (2001) Seasonal Water Table Dynamics of a Southern Appalachian Floodplain and Associated Fen. Journal of the American Water Resources Association 37:105-114.

Moser, L.J. (2009) Hardwood Re-sprout Control in Hydrologically Restored Carolina Bay Depressional Wetlands. M.S. Thesis, University of Kentucky.

Murdock, N.A. (1994) Rare and Endangered Plants and Animals of Southern Appalachian Wetlands. Water, Air, & Soil Pollution 77:385-405.

Nelson, D.W. and L.E. Sommers (1982) Total carbon, organic carbon, and organic matter. In: A.L. Page, R.H. Miller, D.R. Keeney (eds.) Methods of Soil Analysis, Part 2. Chemical and microbiological properties, 2nd ed. ASA-SSSA, Madison, WI.

O'Driscoll, M.A. and D.R. DeWalle (2010) Seeps Regulate Stream Nitrate Concentration in a Forested Appalachian Catchment. Journal of EnvironmentalQuality 39: 420-431.

Ogle, Y. and P. Somers (2008) White Fringeless Orchid *Platanthera integrilabia*: Conservation Status. In: Nature Serve (2008). Available via DIALOG. http://www.cumberlandhcp.org/files/natureserve/Plants_10.23.08/White_Fringeless_Orchid_10.13.08.pdf . Accessed October 23, 2010.

Pearson, A.J., N.P. Snyder and M.J. Collins (2011) Rates and Responses of Channel Response to Dam Removal with a Sand-Filled Impoundment. Water Resources Research 47:1-15.

Pickens, R.M. and C.H. Jagoe (1996) Relationships Between Precipitation and Surface Water Chemistry in Three Carolina Bays. Archive for Hydrobiology. 137:187-209.

Pittillo, J. Dan (1994) Vegetation of Three High Elevation Southern Appalachian Bogs and Implications of Their Vegetational History. Water, Air, & Soil Pollution 77:333-348.

Rossell, I.M., et al. (2009) Succession of a Southern Appalachian Mountain Wetland Six Years Following Hydrologic and Microtopographic Restoration. Restoration Ecology 17:205-214.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. (2002) (eds), Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Schwartz, F.W. and Hubao Zhang (2003) Fundamentals of Groundwater. New York, New York.

Scurlock, J. M. O., G. P. Asner, and S. T. Gower. 2001. Global Leaf Area Index Data from Field Measurements, 1932-2000. Data set. Available on-line [http://www.daac.ornl.gov] from the Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.

Sheldrick, B.H. and C. Wang (1993) Particle size distribution. In: M.R. Carter (ed) Soil sampling and methods of analysis. Canadian Society of Soil Science. Lewis Publishers, Boca Raton, FL.

Soil and Plant Analysis Council (2000) Soil pH, and exchangeable acidity and aluminum. In: Soil Analysis Handbook of Reference Methods. Soil and Plant Analysis Council, Inc., CRC Press, Boca Raton, FL.

Soulsby, C., et al. (2007) Inferring Groundwater Influences on Surface Water in Montane Catchments from Hydrochemical Surveys of Springs and Streamwaters. Journal of Hydrology 333:199-213.

Stine, M.B., L. M. Resler, and J.B. Campbell (2011) Ecotone Characteristics of a Southern Appalachian Mountain Wetland. Catena 86:57-65.

Sun, Ge, et al. (2011) A General Predictive Model for Estimating Monthly Ecosystem Evapotranspiration. Ecohydrology 4:245-255.

Sun, G., et al. (2002) A Comparison of the Watershed Hydrology of Coastal Forested Wetlands and the Mountainous Uplands in the Southern US. Journal of Hydrology 263:92-104.

Sun, Ge, et al. (2001) Effects of Timber Management on the Hydrology of Wetland Forests in the Southern United States. Forest Ecology and Management 143:227-236.

Sun, Ge, H.Reikerk, and L.V. Kornhak (2000) Ground-Water-Table Rise After Forest Harvesting on Cypress-Pine Flatwoods in Florida. Wetlands 20:101-112.

Thompson, Y., et al. (2007) Hydrologic and Edaphic Characteristics of Three Mountain Wetlands in Southeastern Kentucky, USA. Wetlands 27:174-188.

United States Army Corps of Engineers (1987) Corps of Engineers Wetlands Delineation Manual. Wetlands Research Program. Technical Report.

United States Department of Agriculture, Natural Resource Conservation Service (2011) The PLANTS Database Available via DIALOG. http://plants.usda.gov Accessed 4 May 2011.

United States Department of Agriculture, Natural Resource Conservation Service (2011) Web Soil Survey via DIALOG http://websoilsurvey.nrcs.usda.gov Accessed 30 Jan 2012.

United States Environmental Protection Agency (1993) Paired Watershed Study Design. Office of Water. 1-8.

United States Fish and Wildlife Service. (1988) National List of Vascular Plant Species that Occur in Wetlands. United States Fish and Wildlife Service Biological Report.

Walter, I.A., R.G. Allen, R. Elliott, M.E. Jensen, D. Itenfisu, B. Mecham, T.A. Howell, R. Snyder, P. Brown, S. Echings, T. Spofford, M. Hattendorf, R.H. Cuenca, J.L. Wright, D. Martin. 2000. ASCE's Standardized Reference Evapotranspiration Equation. Proc. of the Watershed Management 2000 Conference, June 2000, Ft. Collins, CO, American Society of Civil Engineers, St. Joseph, MI.

Warren, R.J., et al. (2007) The Influence of Woody Encroachment Upon Herbaceous Vegetation in a Southern Appalachian Wetland Complex. The American Midland Naturalist 157:39-51.

Weakley, A. S., and M. P. Schafale (1994) Non-Alluvial Wetlands of the Southern Blue Ridge – Diversity in a Threatened Ecosystem. Water, Air, & Soil Pollution 77:359-83.

Weiss, M., F. Baret, G.J. Smith, I. Jonckheere, and P. Coppin (2004) Review of Methods for In Situ Leaf Area Index (LAI) Determination. PartII. Agriculture for Meteorology. 121:37-53.

Yin, L., et al. (2011) Isotopes (δD and $\delta^{18}O$) in Precipitation, Groundwater and Surface Water in the Ordos Plateau, China: Implications with Respect to Groundwater Recharge and Circulation. Hydrogeology Journal 19:429-443.

Yocubal, I., et al. (2004) Environmental Physical Properties. In: Artiola, Janick F., Ian L. Pepper and Mark L. Brusseau (ed) Environmental Monitoring and Characterization,1st edn. Elsevier, New York, pp 207-238.

Zettler, L.W. (1994) Extinction in our own backyard. The American Orchid Society Bulletin.

Zettler, L.W., Neeraj S. Ahuja, and Thomas M. McInnis, Jr. (1996) Insect Pollination of the Endangered Monkey-Face Orchid (Platanthera Integrilabia) in Mcminn County, Tennessee: One Last Glimpse of a Once Common Spectacle. Castanea 61:14-24.

Zettler, L.W., and C.J. Hofer (1998) Propagation of the Little Club-Spur Orchid (Platanthera Clavellata) by Symbiotic Seed Germination and Its Ecological Implications. Environmental and Experimental Botany 39:189-195.

Zettler, L.W., and John E. Fairley, III. (1990) The Status of *Platanthera integrilabia*, an Endangered Terrestrial Orchid. Lindleyana 5:212-217.

Zettler, L.W., and Thomas M. McInnis Jr. (1994) Light Enhancement of Symbiotic Seed Germination and Development of an Endangered Terrestrial Orchid (Platanthera Integrilabia). Plant Science 102:133-138.

Zhao et al. (2010) Water Requirements of Maize in the Middle Heihe River Basin, China. Agricultural Water Management 97:215-223.

Vita

Catherine Hoy was born on September 9^{th}, 1986 in Charleston, West Virginia. She received Bachelor of Science degrees in Biology and Natural Resource Conservation and Management from the University of Kentucky in May 2009. She worked as a Graduate Research Assistant in the University of Kentucky's Forestry Department from January 2010 to January 2012.